THE MAGAZINE THAT FEEDS MINDS

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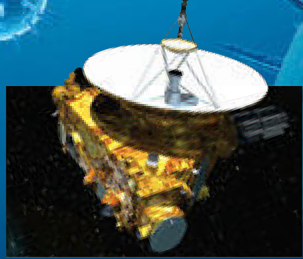

NEW HORIZONS
What will this spacecraft discover en route to Pluto?

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HOW IT WORKS

ISSUE 42

WELCOME

The magazine that feeds minds!

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FEED YOUR MIND

We humans are lucky to have an awesome built-in bug-battling system designed to deal with minor localised outbreaks of sickness. Occasionally, however, strains of extra-resilient microscopic nasties crop up and tour the globe looking for people to target. And such a pandemic could be one of the greatest threats to face the human race. So what has our advanced knowledge of science and medicine achieved in the fight against deadly diseases? And how can we contain such a widescale outbreak? Diseases have long 'plagued' humanity and yet breakthrough vaccines have already eliminated a number of these population killers from circulation. So this issue you'll learn not only the nature of contagions, but also how we are better equipped now than ever to use scientific know-how to combat lethal bugs. Read about some of the newest weapons in our disease-fighting arsenal and also get an expert's perspective.

Elsewhere in the mag you can explore the physics-bending tech inside the latest and greatest fleet of stealth warships and also blow your mind with the inconceivably massive scale of a supergalaxy.

Enjoy the issue.

Helen

Helen Laidlaw
Editor

Meet the team...

Dave
Ed in Chief
Recycling is certainly the way forward, but without a host of hi-tech machines, it would never be possible...

Robert
Features Editor
Writing about the awe-inspiring Angkor Wat was a real joy. I'd love to go to Cambodia to see it in person.

Ben
Features Editor
I struggle to comprehend the scale of supergalaxies, but our feature really puts the universe into perspective.

Adam
Senior Sub Editor
Pandemics often provoke doom and gloom, so it was great to learn how far we've come in treating killer bugs.

The sections

The huge amount of info in each issue of How It Works is organised into these sections:

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The magazine that feeds minds!

MEET THE EXPERTS

Find out more about the writers in this month's edition of How It Works…

Alexandra Cheung
Pandemics

Alex leapt at the chance to write our cover feature on the science of deadly outbreaks this month, as she finds them fascinating. So to learn the difference between a pandemic and an epidemic turn to page 12.

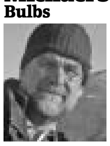
Luis Villazon
Horses

As well as being a keen rider, zoology pro Luis has also spent a lot of time studying the anatomy and gaits of horses and other grazing animals, so he was the perfect man to write our equine article.

Vivienne Raper
Mount St Helens

Vivienne loves working on 'groundbreaking' features and this issue is no exception as she reveals how the eruption of Mount St Helens in Washington State caused a mountain to split in two.

Michael Scott
Bulbs



Botanist Michael has a wide interest in the natural world and was awarded an OBE in 2005 for 'services to biodiversity conservation in Scotland'. This issue he's revealing the yearly cycle of a bulb.

Giles Sparrow
Supergalaxies

Giles studied Astronomy at University College London, and Science Communication at Imperial College, so he was more than qualified to write our great Space feature on galaxy clusters.

How do ballistic tongues work? Find out on page 59

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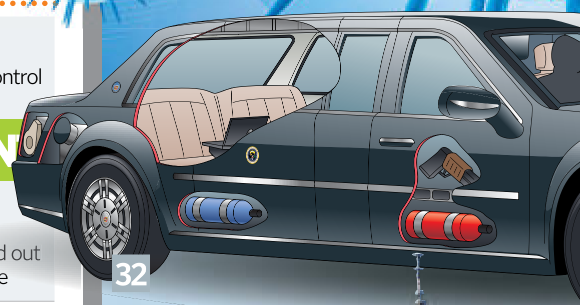

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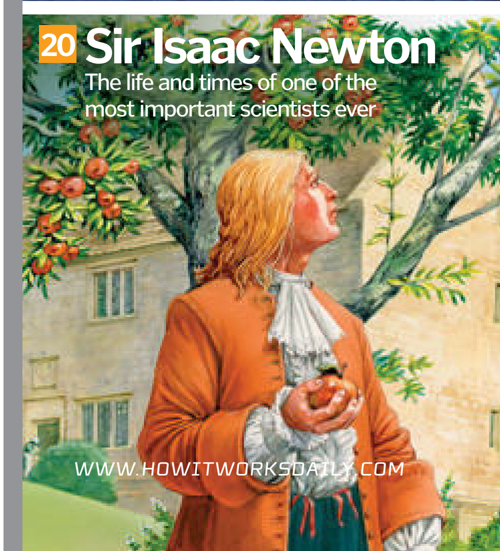

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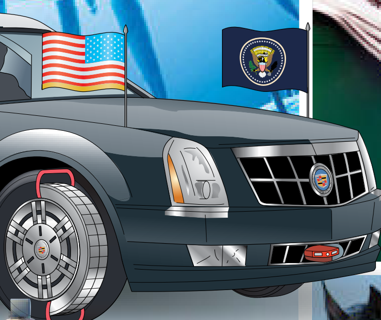

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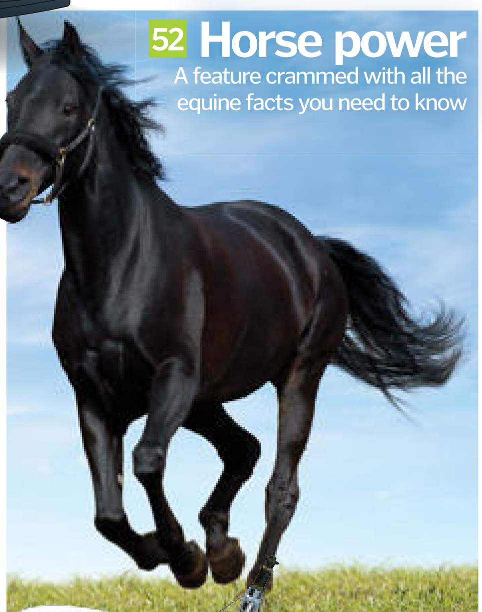

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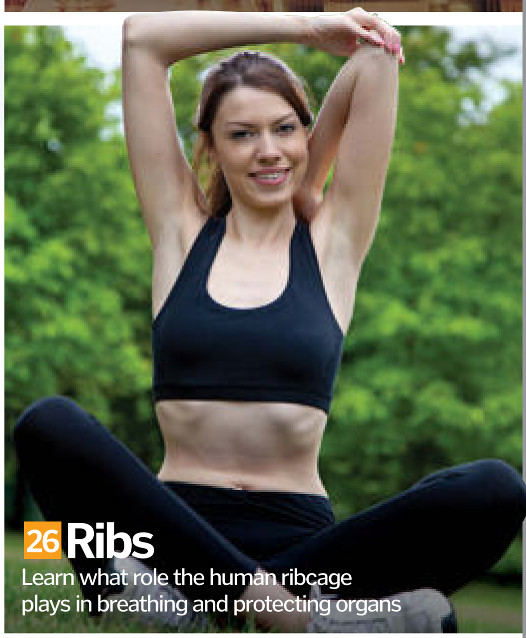

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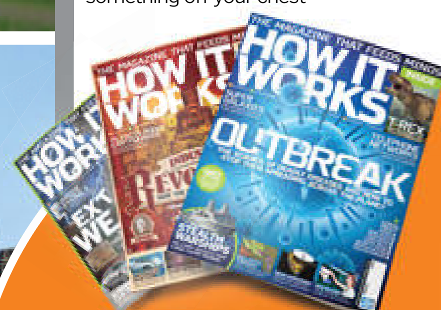


Go to page 92 for great deals

Algae trigger a crimson tide in Australia

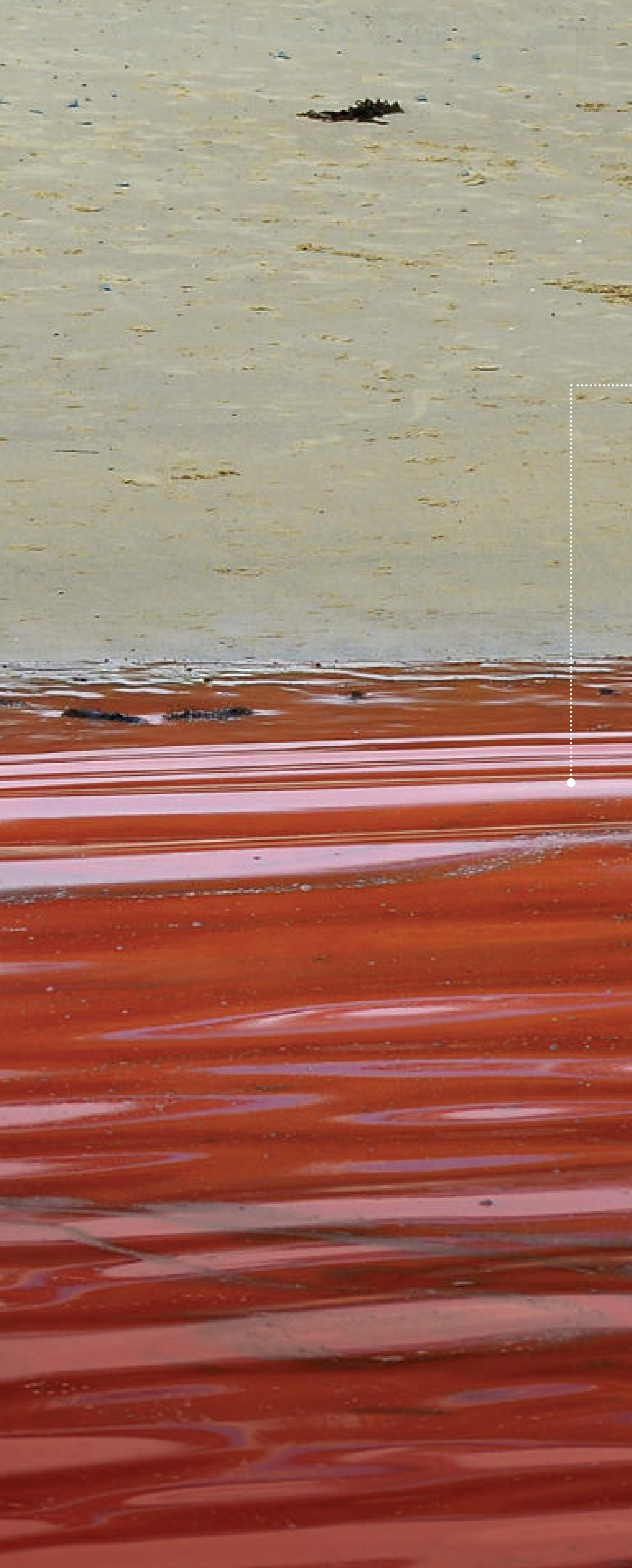
Millions of algae have radically transformed stretches of the Australian coast, turning the normally crystal blue waters red

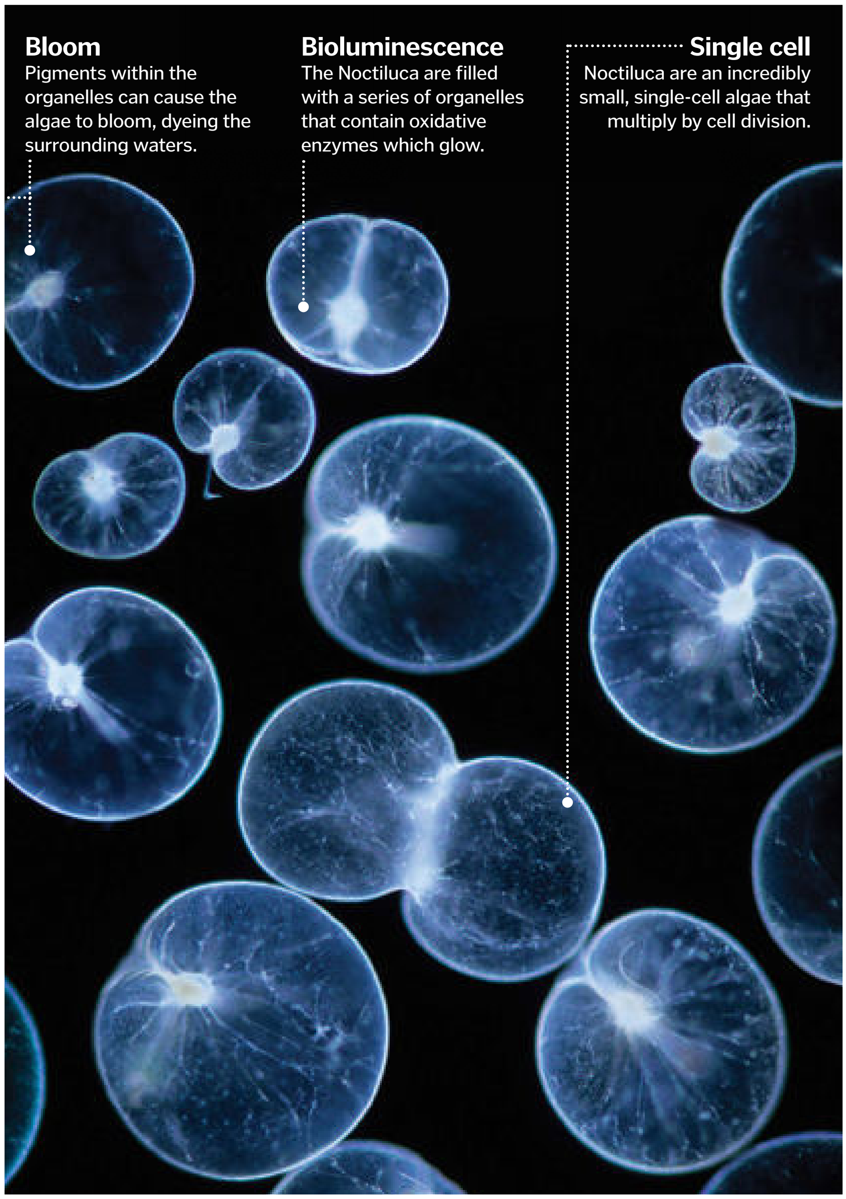
A rare natural phenomenon caused when vast quantities of algae (Noctiluca scintillans) converge en masse – or bloom – has dyed the typically blue waters of the Australian coastline blood red. So far the blooming algae have forced the New South Wales Office of Water to close a number of the country's most famous beaches, including the perennially popular Bondi Beach, and led to widespread disruption to both locals and tourists looking to cool off in the summer heat.

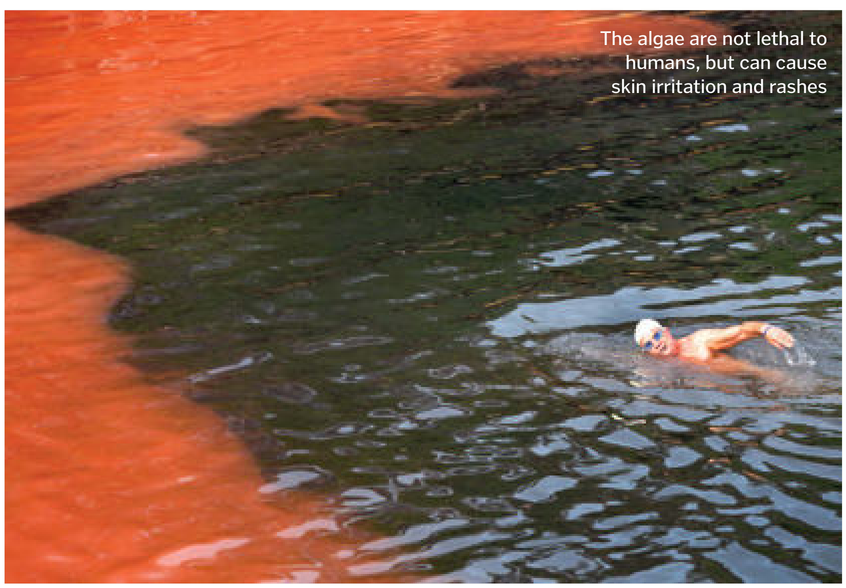
Noctiluca scintillans, which are sometimes referred to as 'sea sparkle', are a free-living, non-parasitic, marine-dwelling species of dinoflagellate that are well known for their bioluminescence. This bioluminescence, caused by the algae containing thousands of spherical organelles filled with oxidative enzymes, means they glow brightly in various colours when amassed. Red and green blooms are the most common, with the colour determined by the particular pigments in the algae's organelles.

While this type of algae are not in themselves toxic, due to their voracious diet of phytoplankton, they can – under the right conditions – accumulate and excrete high levels of ammonia. The poisoned waters can then be lethal to other local marine life. While these levels of ammonia are not strong enough to kill humans, it is capable of causing irritation to the skin and painful rashes.

Speaking on the outbreak of the algae, a spokesperson from the Office of Water said it was likely the result of an upwelling of colder, nutrient-rich water and that "there are some possible risks to human health and for this reason [the beaches] will remain closed until the algae dissipate."






The algae are not lethal to humans, but can cause skin irritation and rashes

"The blooming algae have forced a number of the country's most famous beaches to be closed"

GLOBAL EYE NEWS

An artist's concept of Makemake, a dwarf planet about two-thirds the size of Pluto found in the Kuiper Belt

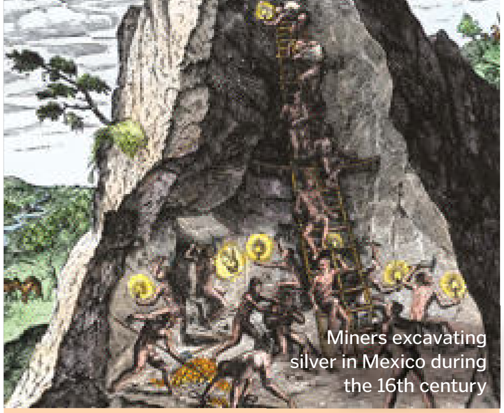
Dead world revealed

A dwarf planet located 4 billion miles from Earth has been revealed to have no atmosphere

Thanks to an extremely rare stellar occultation, where the dwarf planet Makemake passed in front of a distant star, astronomers at the European Southern Observatory (ESO) could determine for the first time whether or not it had an atmosphere.

Previous reports had indicated it did have a very thin atmosphere similar to that found on Pluto, however after analysing the icy mini-planet – which lies in the Kuiper Belt – during the occultation, it became clear that this was not the case. Speaking on the discovery, Dr José Ortiz of the Institute of Astrophysics of Andalucía said: "As Makemake passed in front of the star and blocked it out, the star disappeared and reappeared very abruptly, rather than fading and brightening gradually.

"This means the little dwarf planet has no significant atmosphere. It was thought Makemake [stood] a good chance of having developed an atmosphere. That it has no sign of one at all shows just how much we have yet to learn about these mysterious bodies. Finding out about Makemake's properties for the first time is a big step forward in our study of the select club of icy dwarf planets."



Miners excavating silver in Mexico during the 16th century

English coins had Mexican origins

Chemical studies are revealing that vast quantities of silver dug out of Mexican mines were used to create English coins during the 16th century, solving a centuries-old mystery that left the route and eventual destination of the precious metal unknown.

The discovery has been made by a team of researchers based at the École Normale Supérieure in Lyon, France, who have been analysing a variety of coins dating from 1317 right through to 1640 for their metal content, which are variations of lead, copper and silver.

So far their reports have revealed that coins struck before the reign of Mary I – beginning in 1553 – are packed with ore that is over 220 million years old, indicating it likely came from the ancient rocks in central Europe. However, coins struck later contain a large proportion of silver that is less than 50 million years old, suggesting a Mexican origin.

The research team believes this implies a far more complex westward trade route during this period than previously thought, with many Mexican mines also contributing metals to the established eastward trade route to China.

Extinct reptile to be resurrected

A tortoise species made famous by its last surviving member, Lonesome George, is to be brought back to life

Despite being officially extinct since June, the subspecies Pinta Island tortoise (Chelonoidis nigra abingdonii) that became well known for only having one living specimen – the recently deceased Lonesome George – is to be brought back to life. George was estimated to be around 100 years old when he died.

The scientific venture has been proposed by a group of scientists working at Yale University, who prior to Lonesome George's death took a series of DNA samples from 1,600 tortoises on the Galápagos Islands – 17 of which are strands from the Pinta variety. By crossbreeding these particular animals in a controlled manner, a 100 per cent pure Pinta species could be re-created, the scientists say.

If reintroduced, the Pinta Island tortoise would rejoin the surviving ten species remaining in the region, a number that was once far greater but suffered massively from human predation and development.

George pictured prior to his death on 24 June 2012

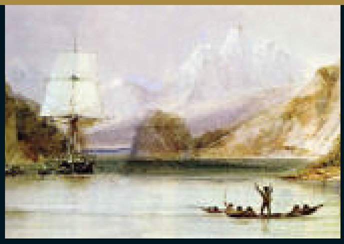
This day in history

27 December: How It Works issue 42 goes on sale, but what

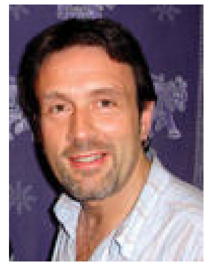
537 CE
Hagia Sophia
The Hagia Sophia church (pictured right) – now a museum – is completed in Istanbul, Turkey.

1512
Laws of Burgos
The Spanish Crown issues the Laws of Burgos, which govern interaction between settlers and native Indians as the New World is colonised.

1831
Darwin sets off
Charles Darwin embarks on his journey aboard the HMS Beagle (right) to South America, during which he starts to form his theories of evolution.



The science of sci-fi



Meet Professor Mark Brake, the astrobiologist turned TV consultant who ensures the science fiction of Doctor Who is rooted in science fact and how this paves the way for the real-world tech of tomorrow

How It Works: To kick off, please tell us a little about your background.

Mark Brake: For about a decade I was professor of science communication at the University of Glamorgan, Wales, where I created the world's first degree in science and science fiction, as well as the first degree in astrobiology. For the last three or four years, I have gone freelance, mostly concentrating on writing, but I am also undertaking a number of scientific roadshows and consulting on the Doctor Who Experience in Cardiff.

HIW: Could you summarise what your latest book *Alien Life Imagined* is about?

MB: In a nutshell it's a history of earthly ideas of how aliens might look and behave. What it does is explore the evolution of those ideas, behind the science and the culture. So what stories were written in the past, why they were written and in what context. I think the main surprise the book delivers is that the notion of alien life is not a 20th-century one – in fact, the idea of aliens is ancient. The concept of life beyond Earth goes back at least to the Ancient Greek Atomists, with people like Epicurus.

Some are rather pure and honest examinations of what life off Earth might be like, while others are for more satirical purposes. For example, in the English language, the first alien contact story was written by the Bishop of Cardiff, Francis Godwin, in 1638, titled *The Man In The Moone*. In the book a man journeys to the Moon by the rather unusual propulsion method of geese. He has harnessed 40 of the birds to fly to the Moon, where he finds a rather sophisticated civilisation. This civilisation is equipped with devices akin to mobile phones and lives in a [utopian] society.

> "I think science fiction is a way of overcoming the shock of the new"

Professor Brake (far left) has been helping to explain the science behind *Doctor Who*

HIW: Do you think sci-fi stories influence the direction of real-world science?

MB: The influence has been so great that billions of pounds have been spent looking for ET. All the influential scientists have been massive sci-fi fans and they've bought into it hook, line and sinker. The mission statement for our current view of the universe is that there *should* be life elsewhere. I mean, as of August this year we have discovered 770 exoplanets and NASA believes there are approximately 2 billion Earth-like worlds in our galaxy alone.

I think sci-fi stories are often used to bridge the gap between what we currently know and what is coming within our horizons – it's a way of overcoming the shock of the new. I mean, look at how HG Wells' and Jules Verne's science fiction helped introduce and develop the idea of rocket technology – all the rocket pioneers such as Robert Goddard were huge fans of those authors. There's even a letter in which Robert Goddard writes to HG Wells to thank the author for making him what he became.

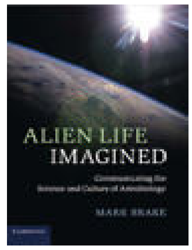
HIW: Do you feel shows like *Doctor Who* help to excite young people about science?

MB: I think there is a romance associated with exploration of the unknown. For example, in the Science And Fiction Of *Doctor Who* roadshow the worst thing I could do would be to point out how everything in the TV show is inaccurate. In *Doctor Who* there are four main themes: space, time, machine and monster – which are arguably the major themes in any science fiction. So, for instance, in the space theme, we explore how *Doctor Who* deals with the topic – analysing the ideas of evolving space and landscapes plus exoplanet existence, and the fact that the show has been talking about these things for 50 years, despite real-world science only discovering them much later.

HIW: Lastly, are there any recent projects you would like to tell our readers about?

MB: As well as *Alien Life Imagined*, I also have a kids' book out – *The Alien Hunter's Handbook*. I'm currently working on its follow-up – *The Time Traveller's Handbook*.

For the full interview visit www.howitworksdaily.com. Mark's latest book, *Alien Life Imagined*, is out now. For more info, visit www.markbrake.com.

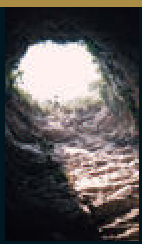


else happened on this day in history?

1922
First aircraft carrier
The Japanese vessel Hosho (right), which translates as 'Flying Phoenix', is the first purpose-built aircraft carrier. It remains in service until 1946.

1945
Bank on it
The World Bank and International Monetary Fund (IMF) are founded.

1966
Mega-cave
The Cave of Swallows (right), the largest-known cave shaft in the world, is found in Mexico.



1978
Democra-sí
Spain votes to become a democracy after 40 years under a dictatorship.

2004
Bright star
Radiation from an explosion on SGR 1806-20 reaches Earth, becoming the brightest extrasolar event ever recorded.

10 COOL THINGS WE LEARNED THIS MONTH

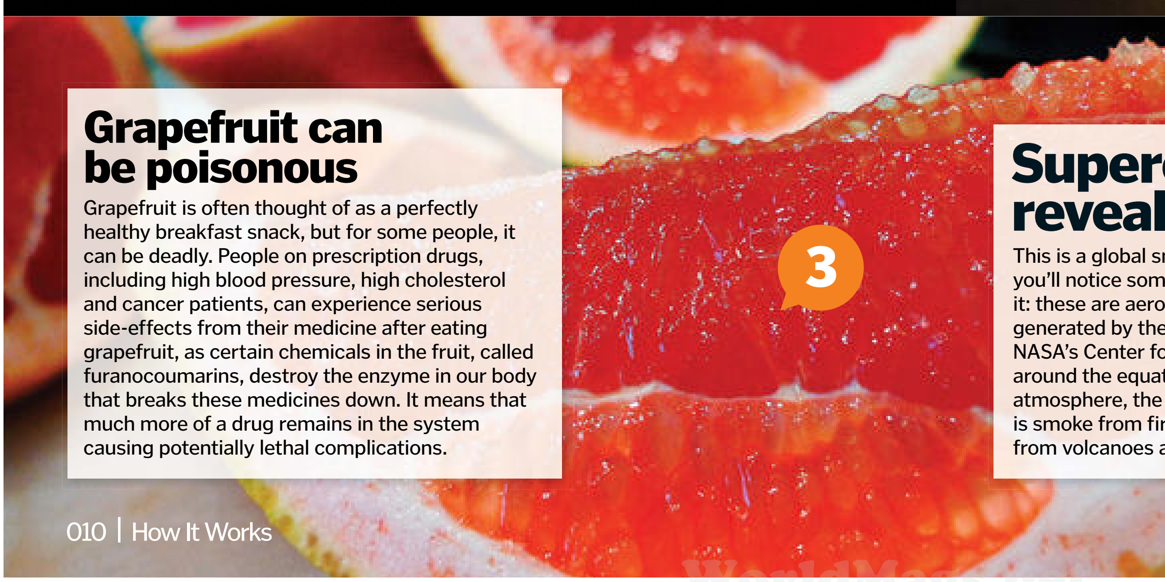
AMAZING TOPICAL FACTS

Fish gobble crabs whole

This is a sand perch, known as a squirrelfish where it's commonly found off Florida. They love the warm, sandy waters of Florida's summer coastline as the area is a haven for its preferred food: crustaceans. Shrimp form a major part of its diet, but so do crabs, which it scoops off the seabed with a disproportionately large mouth. Peeler crabs with soft carapaces are a favourite snack.

Everest isn't Earth's tallest mountain

In fact, at 8,848 metres (29,029 feet) Everest is quite a bit smaller than the tallest mountain on Earth, an accolade that belongs to Mauna Kea in Hawaii (right). When measured from base to summit it is 10,200 metres (33,465 feet) tall, but over 6,000 metres (19,685 feet) of it are below sea level, so it doesn't get as much attention.

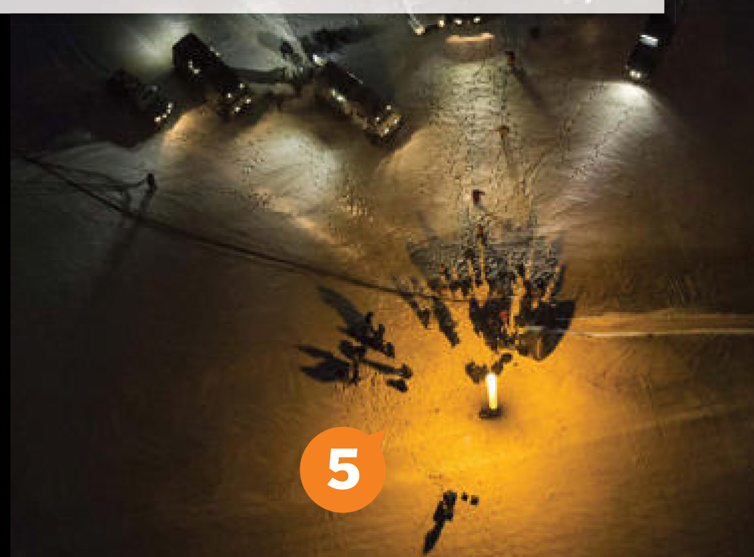


Grapefruit can be poisonous

Grapefruit is often thought of as a perfectly healthy breakfast snack, but for some people, it can be deadly. People on prescription drugs, including high blood pressure, high cholesterol and cancer patients, can experience serious side-effects from their medicine after eating grapefruit, as certain chemicals in the fruit, called furanocoumarins, destroy the enzyme in our body that breaks these medicines down. It means that much more of a drug remains in the system causing potentially lethal complications.

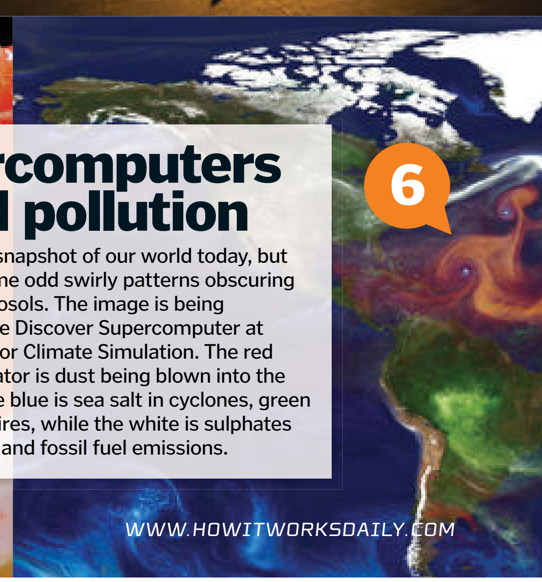
Life exists under 2,800-year-old ice

Bacteria have been discovered in an Antarctic lake that has been sealed beneath ice for about 2,800 years. Scientists have drilled through the ancient ice that sits on top of Lake Vida in the McMurdo Dry Valleys region and have found it teeming with microbes. It's surprising because it's six times saltier than the sea and at -13 degrees Celsius (8.6 degrees Fahrenheit), it's one of the coldest aquatic environments on Earth. This has excited astrobiologists because it bodes well for finding life under the ice on other planets.



LEGO can be controlled from space

This is the Soyuz TMA-05M spacecraft and crew, having touched down in Kazakhstan after successfully completing Expedition 32 to the International Space Station. Their mission, among other things, was to operate a LEGO robot at the European Space Operations Centre in Germany from the ISS in low Earth orbit. This wasn't just for the sake of it though; they were testing a new network protocol called DTN (Disruption Tolerant Networking) that allows for the control of technology on our planet's surface from orbit.



Supercomputers reveal pollution

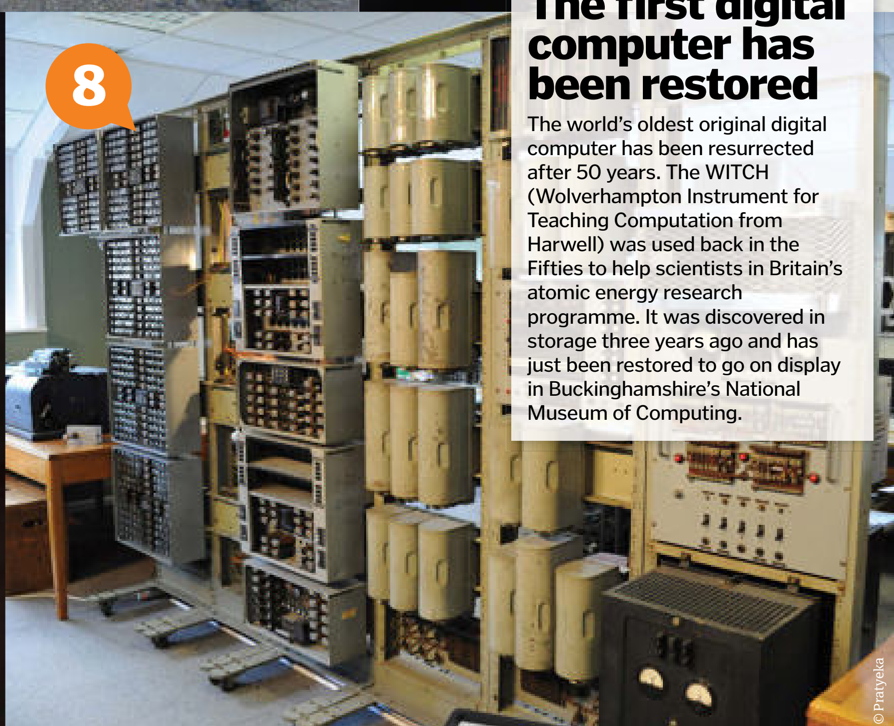
This is a global snapshot of our world today, but you'll notice some odd swirly patterns obscuring it: these are aerosols. The image is being generated by the Discover Supercomputer at NASA's Center for Climate Simulation. The red around the equator is dust being blown into the atmosphere, the blue is sea salt in cyclones, green is smoke from fires, while the white is sulphates from volcanoes and fossil fuel emissions.

7

There are monkeys with mohicans

This cotton-top tamarin, officially known as Saguinus oedipus, is native to the edges of tropical forests of northern Colombia in South America. They're very small, squirrel-sized monkeys, weighing less than 0.5 kilograms (one pound) who take refuge high in the treetops. They also sport a rather impressive hairdo from which their common name is derived.

© Michael Gabler



8

The first digital computer has been restored

The world's oldest original digital computer has been resurrected after 50 years. The WITCH (Wolverhampton Instrument for Teaching Computation from Harwell) was used back in the Fifties to help scientists in Britain's atomic energy research programme. It was discovered in storage three years ago and has just been restored to go on display in Buckinghamshire's National Museum of Computing.

© Pratyeka

9

Smoking can harm the brain

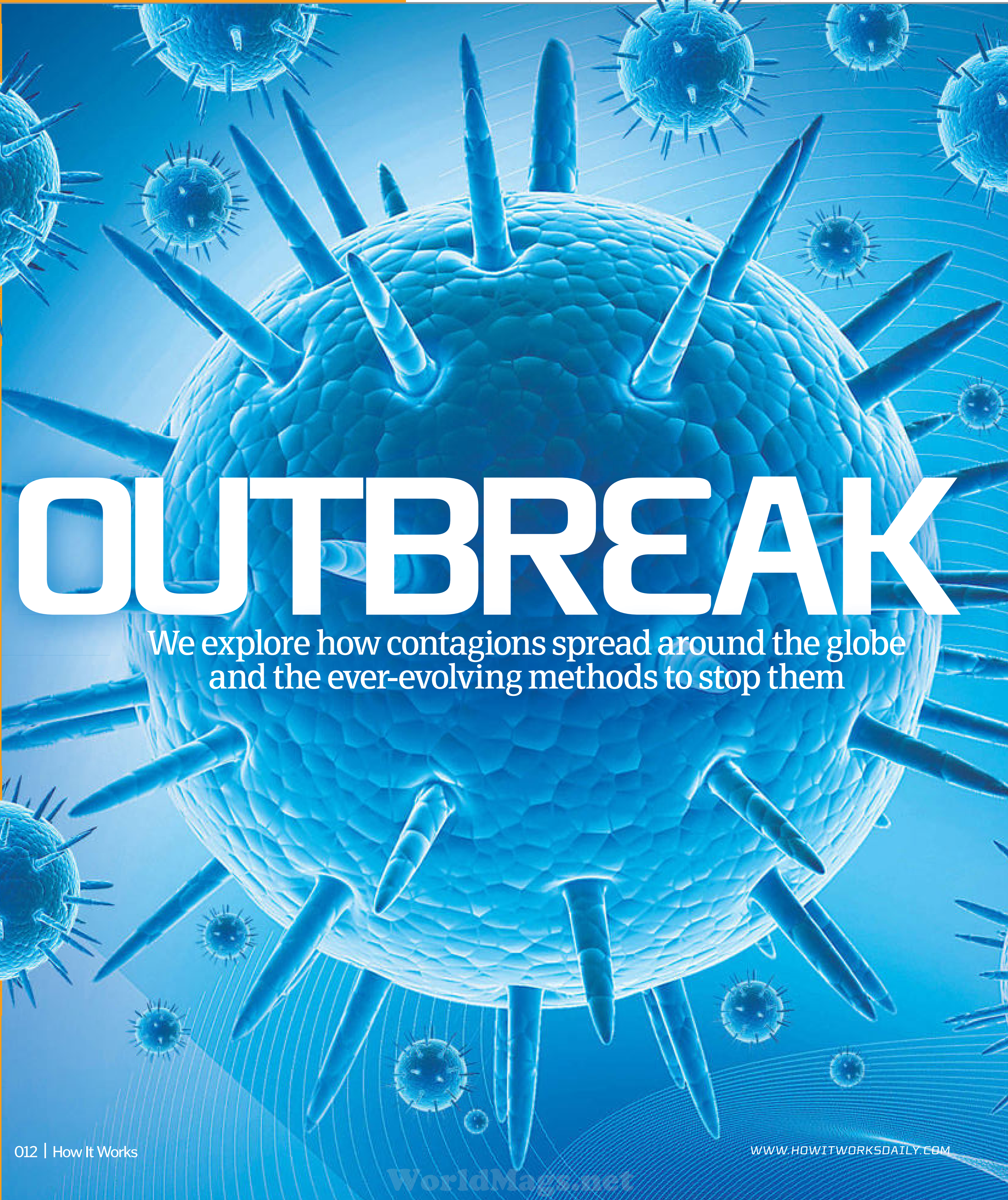
We all know smoking is bad for us, right? Well, here's another reason to give up: a study of 8,800 people by researchers at King's College London has shown a smoking habit damages the areas of the brain that are responsible for memory, learning and reasoning.

10

Pong is 40

Atari's classic bat-and-ball game *Pong* is 40 years old. It was launched on 29 November 1972 as a 'Tele-Game' and became an instant hit around the world. The game was designed by electrical engineer Allan Alcorn, who had no experience in the area but developed *Pong* as an exercise in making games. He created a prototype using a black-and-white TV set in a wooden cabinet with wires soldered into boards.

© Thinkstock; NASA; SPL; Evan Amos



OUTBREAK

We explore how contagions spread around the globe and the ever-evolving methods to stop them

5 TOP FACTS
WEIRD CURES

Scab snorting
1 Practised in India and China, this 17th-century inoculation technique consisted of inhaling powdered scabs from smallpox sufferers. Weird as it sounds, it did provide some immunity.

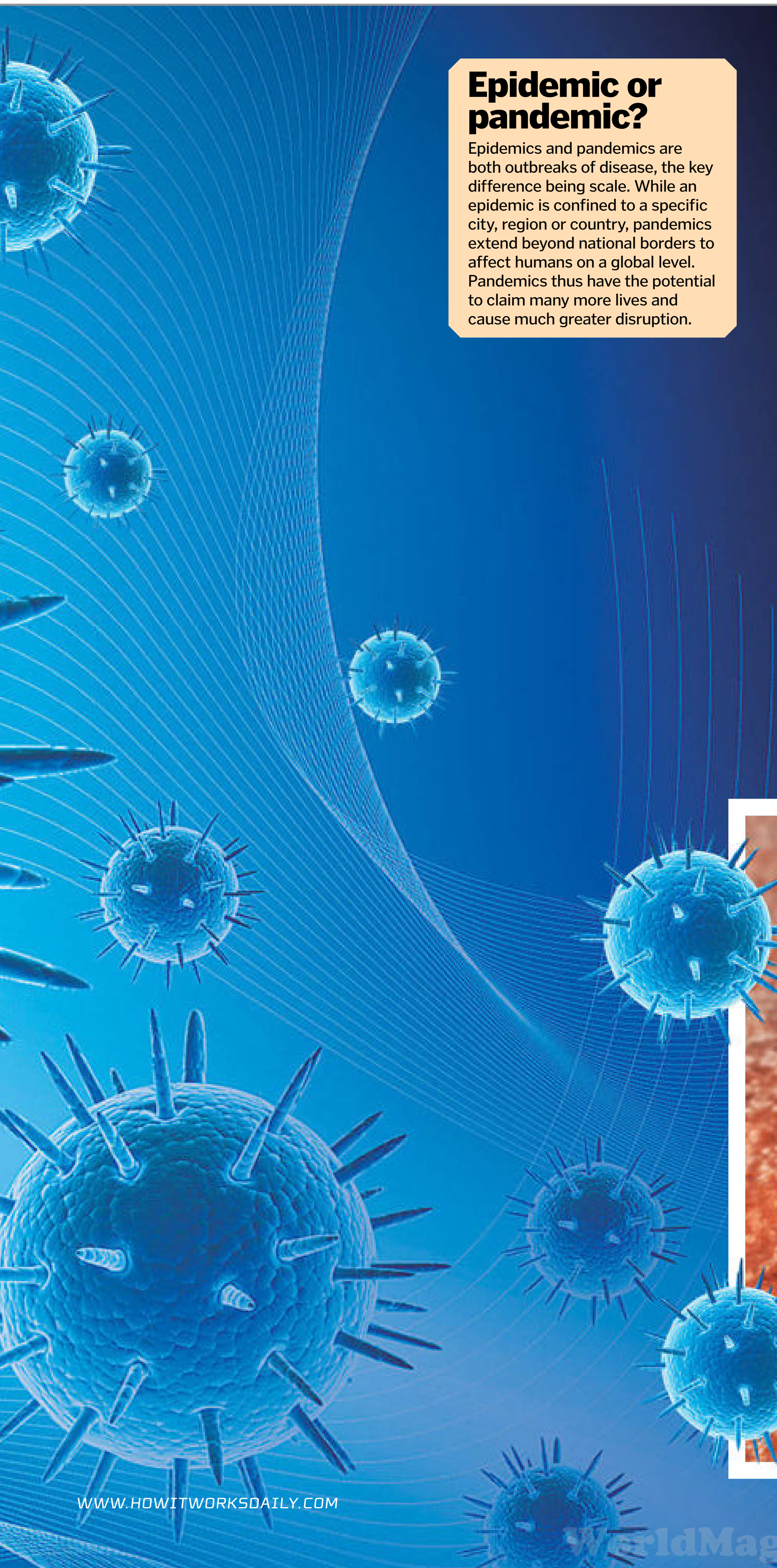
Chicken bottom
2 Strange cures abounded for the Black Death. One trick prescribed by plague doctors was to hold the shaved backside of a live hen against boils to draw out 'pestilence'.

Leeches
3 For 2,000 years, doctors bled patients to purge them of diseases, often with leeches. This long-running (and highly ineffective) tradition was only discredited in the 1900s.

Mercury
4 The treatment for syphilis for centuries was mercury, a very toxic metal. With debilitating side-effects of its own, it did little more than hasten the deaths of its patients.

Tortoise brain
5 Ancient Egyptians developed some effective cures, but their treatment for cataracts was not one. It involved smearing tortoise brains mixed with honey over the eyes.

DID YOU KNOW? *Our most common gene provides no benefit to us, but some viruses use the protein it encodes to infect us*



Epidemic or pandemic?

Epidemics and pandemics are both outbreaks of disease, the key difference being scale. While an epidemic is confined to a specific city, region or country, pandemics extend beyond national borders to affect humans on a global level. Pandemics thus have the potential to claim many more lives and cause much greater disruption.

Human history is punctuated by a number of terrifying pandemics. These global outbreaks of disease will, without a doubt, remain a real threat to humanity for the foreseeable future, however our growing knowledge of medicine and how the diseases work makes us better equipped than ever to fight them.

The word 'disease' encompasses the wide range of ailments from which we can suffer. The ones that cause epidemics and pandemics are infectious diseases – those that can spread from one person to another.

Infectious diseases include everything from the common cold to HIV/AIDS. They are caused by biological agents (or pathogens) – frequently bacteria and viruses but also parasites, fungi and prions (such as bovine spongiform encephalopathy, also known as mad cow disease).

Most micro-organisms living either on or inside our bodies are totally harmless. In fact, our bodies contain up to ten times more bacterial cells than they do human cells! This still leaves a good few handfuls of pathogens intent on ensuring their survival at our expense.

Whether it's the common flu virus or more unusual bugs, these pathogens have evolved a whole arsenal of tricks to hop from one human to another, spreading through coughs and sneezes, bodily fluids and more.

Some even hitchhike on another organism that does all the legwork for them – known as a vector. Malaria is a good example of a vector-dependent disease. Caused by a parasite, malaria is carried by mosquitoes, which spread the illness between humans when they bite them. ▶

The Ebola virus kills up to 90 per cent of those who contract it

"As we're exposed to diseases, our immune systems develop tailor-made antibodies to latch onto attackers"

Despite these clever tactics, it's relatively rare for a pathogen to infect enough people to spark a pandemic. One reason is that our bodies possess a highly effective defence against their onslaught: the immune system.

As we're exposed to diseases, our immune systems develop tailor-made antibodies to latch onto attackers and either neutralise them or earmark them for destruction. Over time, your body builds up a vast catalogue of antibodies. A pathogen's first attack might cause a full-blown infection, but if a repeat invasion occurs, the immune system responds swiftly to defuse the attack.

As a result (and also thanks to vaccination), a substantial proportion of the population is resistant to common diseases, making it hard for these pathogens to infect enough people at one time to cause a pandemic. Chickenpox, for instance, is highly contagious, but after a person has been attacked by it once, their body 'remembers' the intruder and the vast majority are immune to it for life.

Pandemics therefore tend to be triggered by pathogens which we have had very little exposure to and which can catch our immune systems unawares.

Historically, diseases from other countries could do just that. When European settlers arrived in North America, they introduced diseases which Native Americans had never encountered before, such as measles, influenza and smallpox. These pathogens set off waves of deadly epidemics which killed over 90 per cent of the indigenous population.

Nowadays, regular international travel spreads pathogens around, meaning 'old' diseases aren't a threat. The ones to worry about are new diseases (or variants of known diseases), which all come from one source: animals.

The animals most likely to pass on their diseases are our closest relatives, the great apes. The HIV virus, for example, has been traced back to chimpanzees in Africa who were eaten by humans in the first half of the 20th century.

Like many other zoonoses (diseases which cross the species barrier) HIV first infected a few isolated humans, but as the virus evolved it crossed another very important hurdle: it acquired the ability to transmit from one person to another. Once a disease possesses the capability to do this, it really does become a ticking time bomb.

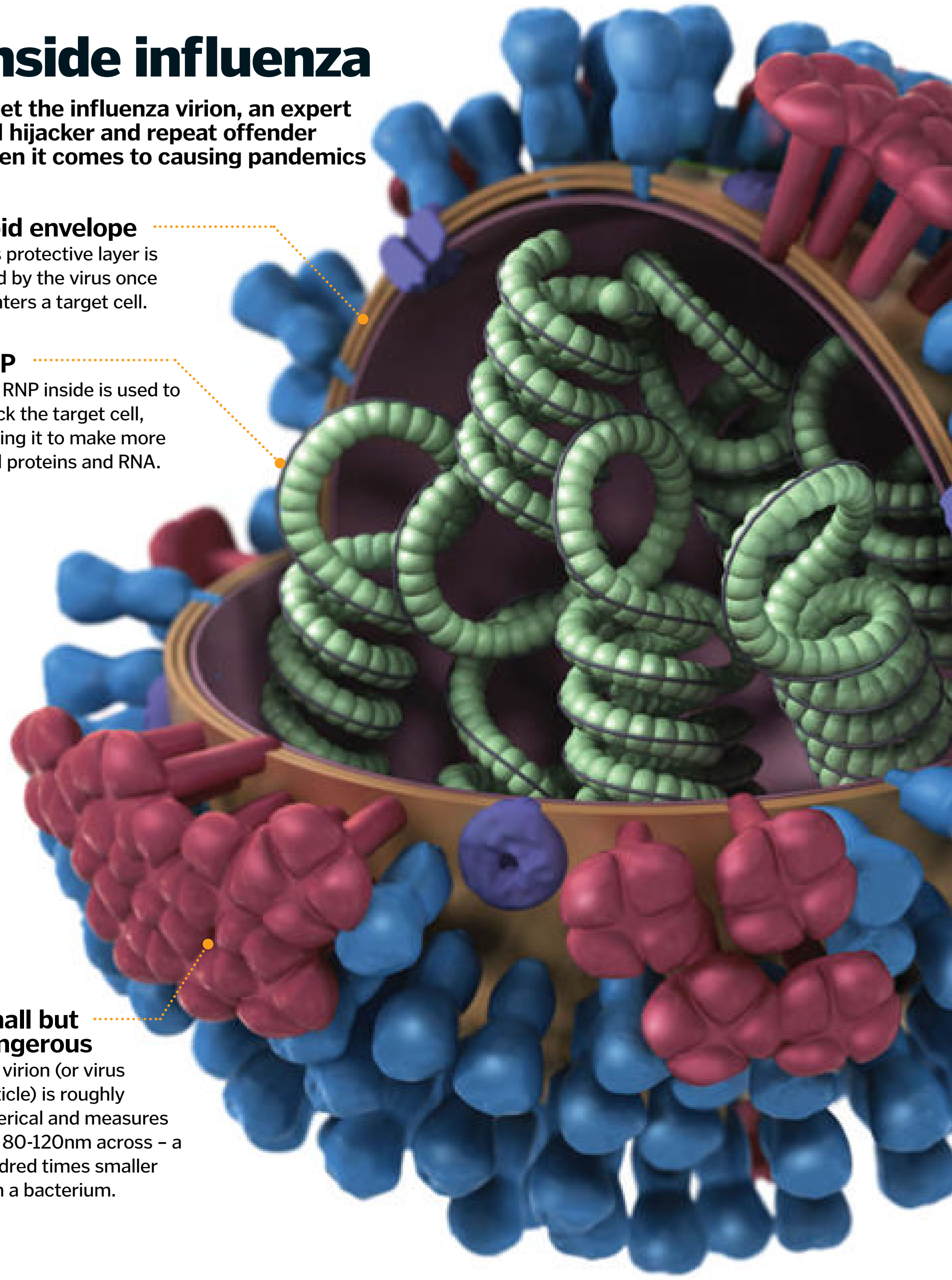
While it's relatively easy for a pathogen to make the leap from an ape to us, or vice versa, much greater leaps are possible. Very few of us come into contact with apes, but we have a much closer relationship with domestic animals. A precursor to the influenza virus which caused the 1918 Spanish Flu is thought to have existed first in wild birds, then in domestic pigs, before jumping over to people.

For millennia humans were entirely at the mercy of disease, but the late-18th century saw the invention of our best weapon against infection: the vaccine.

Vaccines fool the immune system into thinking it's being attacked by a pathogen, stimulating it to create an army of antibodies and killer T-cells specific to this disease. If we ever encounter the real thing, our bodies are therefore primed to fight off the infection.

Inside influenza

Meet the influenza virion, an expert cell hijacker and repeat offender when it comes to causing pandemics



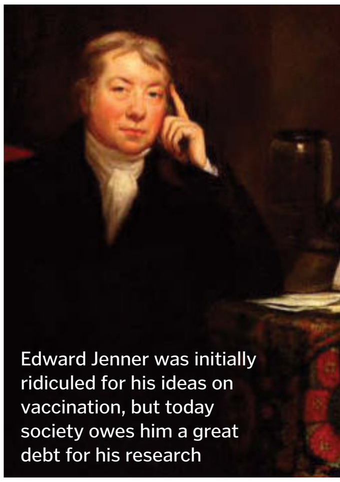
Lipid envelope
This protective layer is shed by the virus once it enters a target cell.

RNP
The RNP inside is used to hijack the target cell, forcing it to make more viral proteins and RNA.

Small but dangerous
The virion (or virus particle) is roughly spherical and measures just 80-120nm across – a hundred times smaller than a bacterium.

To do this a tiny amount of the pathogen (usually attenuated, which means weakened) is injected into the body – this process is known as inoculation. It might come as a surprise but people were actually experimenting with inoculation in China and India as long ago as 1000 BCE. However, it wasn't until 1796 that the first successful vaccination was produced.

Throughout the 18th century, smallpox was a leading cause of death around the world. English physician Edward Jenner noticed that milkmaids who had caught an illness called cowpox seemed to be immune to smallpox. By injecting patients with pus taken from cowpox sores, he was able to confirm his hypothesis and the first vaccine was born. Vaccination was adopted across the globe and smallpox was officially eradicated in 1979.



Edward Jenner was initially ridiculed for his ideas on vaccination, but today society owes him a great debt for his research

1. DEADLY

HIV/AIDS
This pandemic has raged since the early-Eighties, claiming around 25 million lives. Approximately 34 million people currently have HIV across the globe.

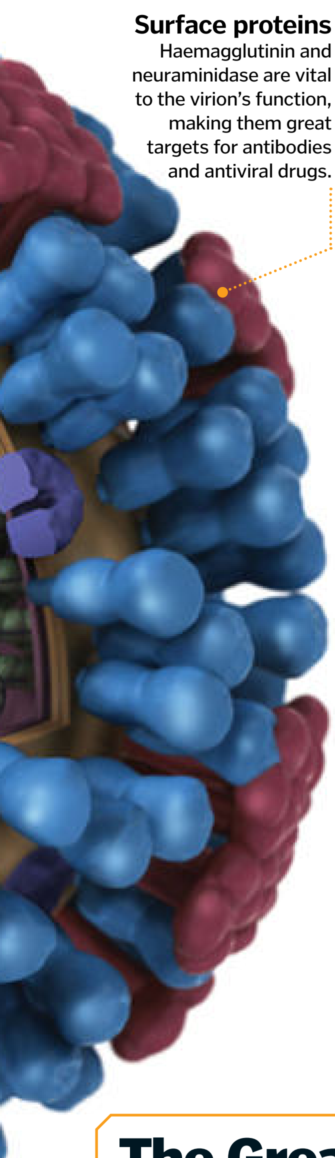
2. DEADLIER

Spanish Flu
A truly global pandemic, some believe that this influenza virus, which emerged in 1918, killed as many as 40-50 million people around the world.

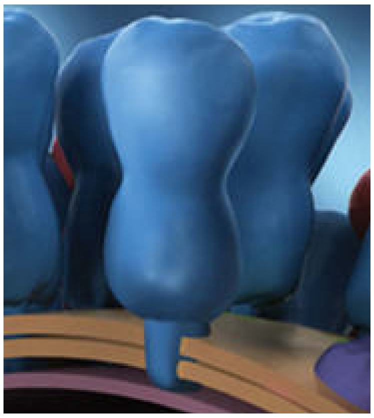
3. DEADLIEST

The Black Death
This infamous bubonic plague outbreak swept across Asia into Europe with a total death toll of roughly 100 million.

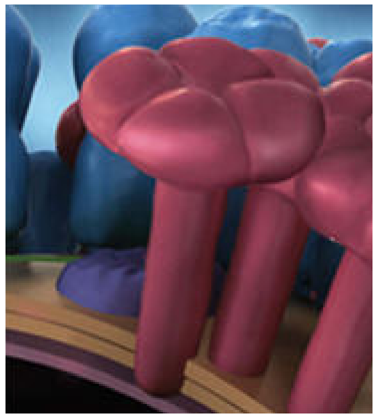
DID YOU KNOW? *The word vaccination comes from the Latin 'vacca' (cow), due to Edward Jenner's cowpox research*



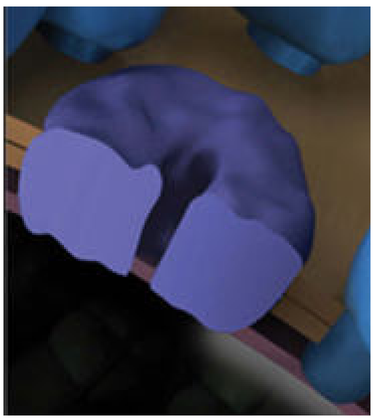
Surface proteins
Haemagglutinin and neuraminidase are vital to the virion's function, making them great targets for antibodies and antiviral drugs.



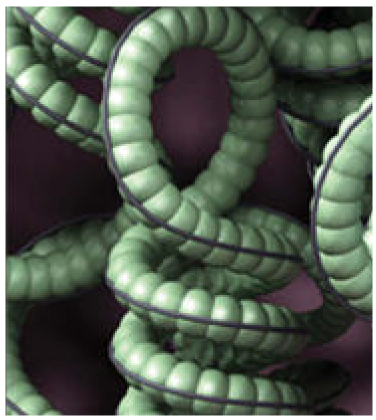
Haemagglutinin
This spike-shaped protein is one of the flu's key weapons, helping the virion stick to a target cell to begin its attack.



Neuraminidase
Once its job is done, the neuraminidase enzyme clips polysaccharide chains allowing the virion to leave the cell.



M2 ion channel
The M2 protein lets hydrogen pass into the virion, increasing its acidity and exposing its RNA.



Ribonucleoprotein
The virion's genetic code consists of six to eight segments of RNA, encased in a protein sheath (making up the RNP).

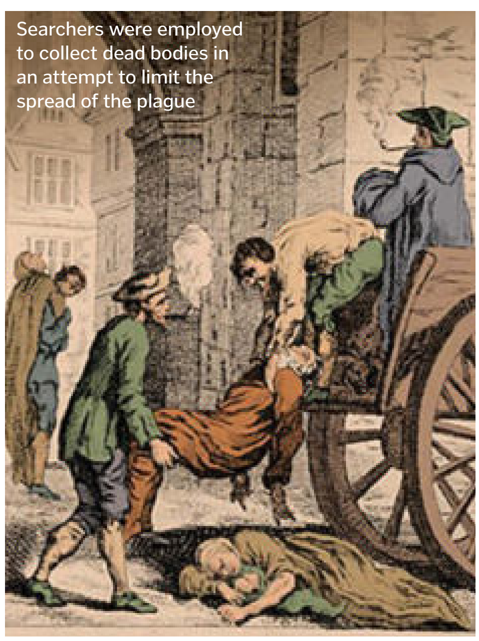
The Great Plague

Probably the deadliest pandemic in human history, the Great Plague, or Black Death, ravaged Europe from 1348-1350, killing up to half of the population in that short time. At its root was the bubonic plague-causing Yersinia pestis bacterium.

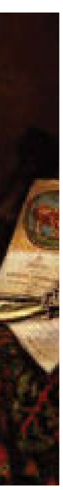
Originating in Asia, the plague first struck in China where it killed approximately 25 million people. It then spread into Europe following the Silk Road. Y pestis bacteria were carried by fleas, who themselves hitchhiked on the rats that thrived in the hulls of merchant ships.

After first landing on the shores of Italy in 1347, the Black Death had swept as far north as England by the following summer and continued onward to Germany and Scandinavia in 1348.

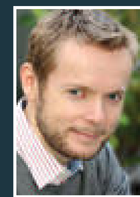
Highly infectious, the disease struck and killed its victims with startling speed. The telltale sign of infection was the appearance of swollen lymph glands – called buboes – typically around the groin, neck and armpits. Sufferers then developed a high fever and began to vomit blood, usually dying within a week of the first symptoms showing. With no effective cure to keep it in check, the plague returned repeatedly for the next 300 years.



Searchers were employed to collect dead bodies in an attempt to limit the spread of the plague



Interview
How to tackle pandemics



London School of Hygiene and Tropical Medicine's Prof John Edmunds explains all

How It Works: What disease do you think will cause the next pandemic?

John Edmunds: Flu! Well, I don't know if it will cause the *next* one, but it will definitely cause a pandemic in the future. As for other diseases, it's hard to predict. There are various surveillance efforts underway to see which pathogens are circulating among animals to gain some understanding of what the most likely pandemics will be. It's still a huge guess frankly, but it's worth keeping track of these diseases and characterising them because, if they do start spreading in humans, we need to know about them.

HIW: How is our track record for detecting and dealing with pandemics?

JE: We're very good at responding to these things now. There's a lot of fuss about the 2009 flu pandemic, but that virus was sequenced from top to tail in a matter of days after the first cases were isolated. We knew an awful lot about it very quickly. The same goes for the SARS virus.

HIW: Could a pandemic end humanity?

JE: I suppose it could. But do I think it will? No. Medical and allied sciences like epidemiology and modelling are so strong now. But there's a significant risk to certain populations – especially the countries that don't have the facilities to respond. Take SARS – we got on top of it just in time. The countries that it initially spread to had well-functioning health systems. But there are other countries that aren't in that category, like India or Indonesia. What if it had jumped from there to Africa? Would we have been able to stop it spreading in those settings? It would have been incredibly difficult. So I think it's unlikely a pandemic would wipe out humanity, but it could cause huge damage, particularly in some areas of the world with weak health infrastructure.

For more about Professor Edmunds' work, visit the flu outbreak monitoring site: http://flusurvey.org.uk.

"HIV has one of the highest mutation rates, reshuffling its genes constantly to change the shape of its proteins"

Jenner's landmark work with smallpox paved the way for a wide variety of vaccines to be created. In the late-19th century, microbiology pioneer Louis Pasteur developed vaccines against anthrax and rabies. A key innovation was that Pasteur's method consisted of treating pathogens to render them totally harmless.

In the following century, new vaccines were developed at an astonishing rate. American microbiologist Maurice Hilleman alone led the invention of over 30 vaccines (including those against measles, mumps, hepatitis A, hepatitis B and meningitis). Widespread vaccination for common pathogens means that most of the population is now resistant to them, preventing epidemics and forever changing our relationship with diseases which plagued humanity for centuries or even millennia.

But while it is easy to create vaccines against some diseases, others are far more elusive due to the rapid changes they undergo. The most notorious of these shape-shifters is the HIV virus. HIV has one of the highest mutation rates known, reshuffling its genes constantly to change the shape of its surface proteins. By modifying its disguise, it makes itself unrecognisable to antibodies, dodging the immune system's guardsmen. Developing a vaccine against HIV is therefore a tremendous challenge. HIV also attacks the immune system directly.

Other diseases, such as influenza, are relatively easy to vaccinate against once a new strain has been identified, however the unpredictability of outbreaks means that they are still a real threat. Influenza exists principally in wild birds, but every so often a new strain of the virus will become transmissible between humans, sparking epidemics and even pandemics, such as the HN51 virus. The time and location of these spillovers are virtually impossible to predict, though monitoring wild birds is one way of keeping an eye out for new strains of the virus which have the potential to make the leap.

In a number of ways, modern society leaves us more exposed to pandemics than we were in the past. For one thing, nowadays about 50 per cent of us live in cities where we come into contact with a huge number of people on a daily basis, facilitating the spread of disease.

The ever-growing number of international flights also accelerates transmission, allowing pathogens to hop from one continent to another in a matter of hours. In 2003 SARS (severe acute respiratory syndrome) spread to 29 countries across three continents in just a few months.

Despite this, our understanding of pathogens is continually improving. SARS was a brand-new disease, but the global medical community rapidly got to know its idiosyncrasies and brought it under control. While we don't have a vaccine for HIV yet, treatments have improved dramatically, and public health measures have helped to reduce or stabilise infection rates in most countries.

Pandemics will inevitably continue to strike in years to come, but we can rest assured that we are better armed than ever in our eternal battle against pathogens.

How pandemics go global

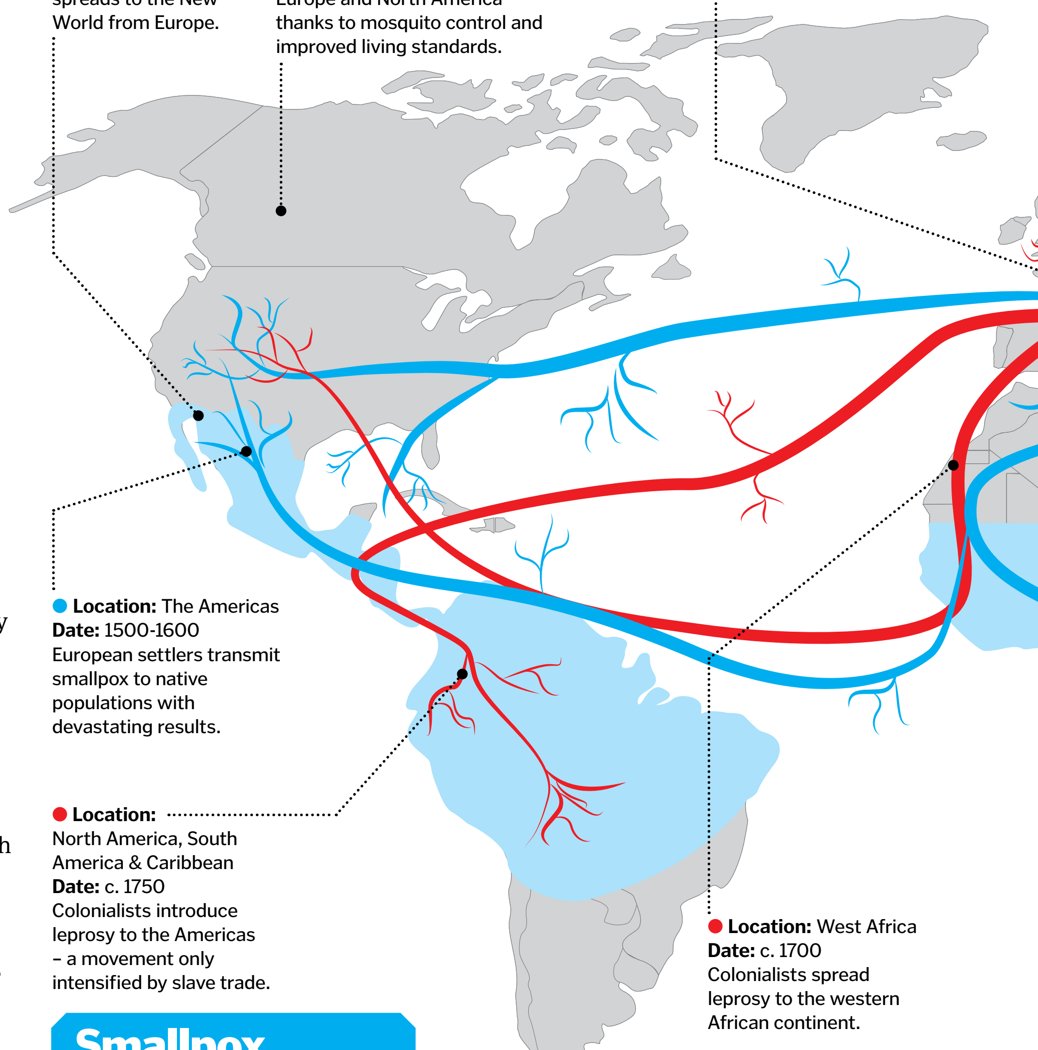
Track how three of the most common diseases spread around the world…

Smallpox **Leprosy** **Malaria**

Location: Americas
Date: c. 1600
Following a familiar pattern, malaria spreads to the New World from Europe.

Location: North America & Europe
Date: 1950s
Malaria largely disappears from Europe and North America thanks to mosquito control and improved living standards.

Location: Europe
Date: c. 327 BCE
Alexander the Great's army returns from India, bringing leprosy to Europe.



Location: The Americas
Date: 1500-1600
European settlers transmit smallpox to native populations with devastating results.

Location: North America, South America & Caribbean
Date: c. 1750
Colonialists introduce leprosy to the Americas – a movement only intensified by slave trade.

Location: West Africa
Date: c. 1700
Colonialists spread leprosy to the western African continent.

Smallpox

Following the discovery of a vaccine this acute and often-fatal contagious disease has now been eradicated. Smallpox develops in those exposed to the Variola virus. Following exposure the virus incubates for a period of usually 12-14 days during which time the individual is not contagious. After incubation, however, the sufferer will experience feverishness, sickness and headaches before developing the dreaded rash. This is when the victim is at their most contagious. The itchy red spots become fluid-filled pustules that scab over. The victim will remain contagious till all the scabs fall off.

Leprosy

Though an ancient illness, leprosy – or Hansen's disease – remains a highly infectious, chronic ailment today. This isolating disease is caused by a microbacterium in the environment – probably in the form of nasal mucus droplets – which is absorbed into its victim's bloodstream. Leprosy affects the skin and nerves, causing lesions and patches on the skin as well as loss of sensation and weakness in the hands, feet and face. While historically people believed that the disease caused parts of its sufferers to 'fall off' it is in fact the numbness caused by nerve damage that leads leprosy sufferers to injure themselves. For example, they could burn themselves on a flame and not even feel it. Today the disease is curable with the help of antibiotics.

THE STATS
SPANISH FLU

FIRST REPORTED **1918** | TYPE **H1N1 subtype A** | DEATHS **>25mn**

CASE FATALITY RATE **20%** | INFECTION RATE **50%** | LAST REPORTED **1920**

DID YOU KNOW? *The World Health Organisation uses a six-stage scale to classify the severity of an influenza pandemic*

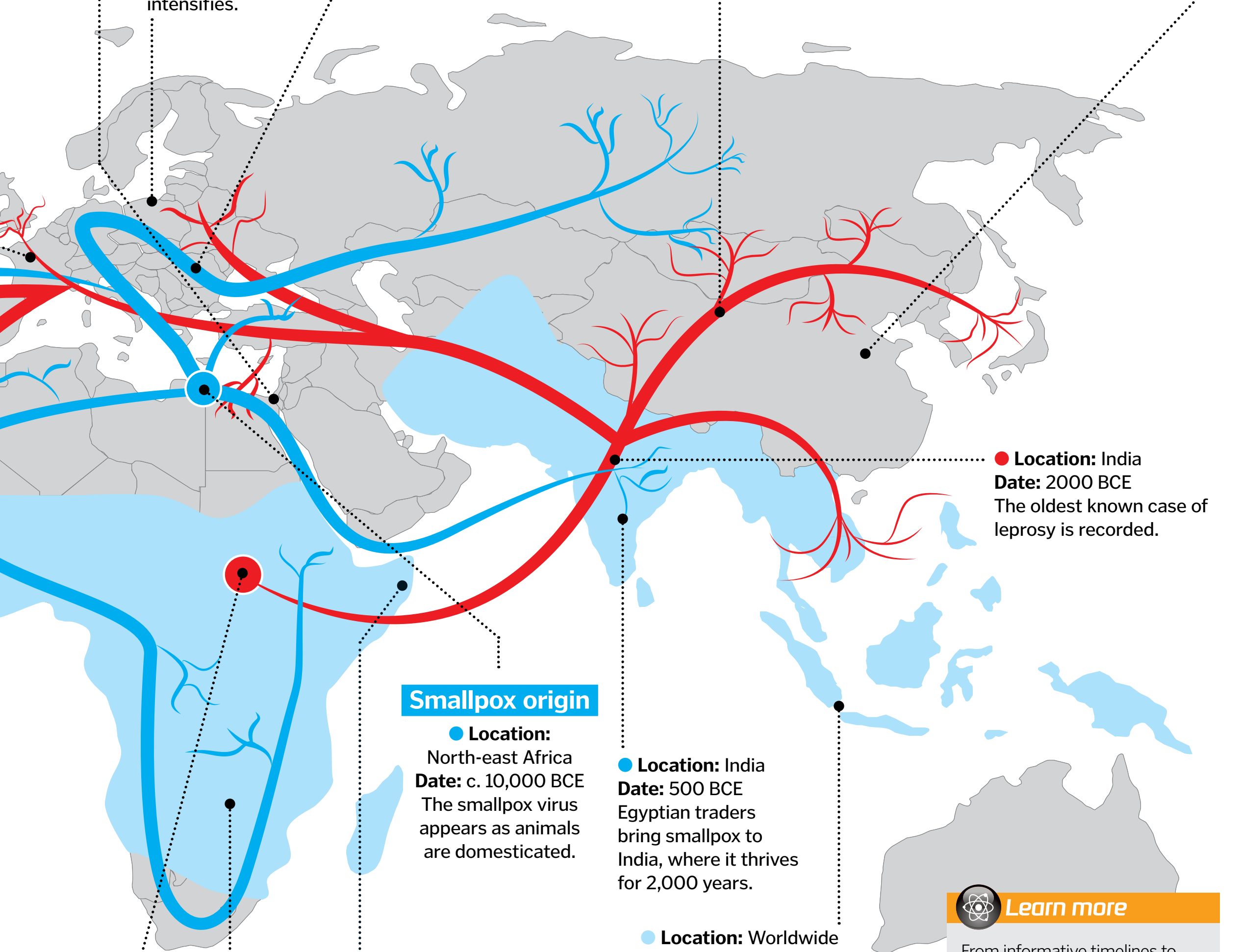
Location: Egypt
Date: 1145 BCE
Earliest evidence of smallpox DNA found in mummies.

Location: Europe
Date: c. 1500
Malaria extends its reach into northern Europe as trade intensifies.

Location: Europe
Date: c. 1500
Smallpox becomes established, possibly as a result of increased travel during the Crusades.

Location: China
Date: c. 250 BCE
First documented cases of leprosy in China, probably spread by traders.

Location: China
Date: 2600 BCE
Earliest written report of malaria in China.



Location: India
Date: 2000 BCE
The oldest known case of leprosy is recorded.

Smallpox origin
Location: North-east Africa
Date: c. 10,000 BCE
The smallpox virus appears as animals are domesticated.

Location: India
Date: 500 BCE
Egyptian traders bring smallpox to India, where it thrives for 2,000 years.

Location: Worldwide
Date: c. 1850
At the peak of its spread, malaria threatens half of the world's population.

Malaria origin
Location: Africa
Date: 10,000 BCE
Like modern man, malaria emerges in Africa and follows humans migrating into Eurasia.

Location: Somalia
Date: 1977
Last reported case of naturally contracted smallpox.

Leprosy origin
Location: East Africa
Date: c. 40,000 BCE
Leprosy bacterium believed to originate in eastern Africa or the Middle East.

Learn more
From informative timelines to fascinating articles, find a mine of information on diseases and the development of the vaccine at **www.historyofvaccines.org** – an online resource that was put together by the College of Physicians of Philadelphia.

Malaria

Though malaria is not contagious (ie not passed from person to person like a cold) this disease endemic to the tropics is a widespread killer. It's transmitted by the presence of a certain single-celled parasite in the saliva of female mosquitoes. When the mosquito pierces the skin of her victim with a straw-like proboscis mouthpart to obtain blood, she also releases some saliva which acts as an anticoagulant to keep the blood flowing. In doing so she also passes deadly parasites into the victim's bloodstream. Flu-like symptoms usually occur between ten days and four weeks after infection, however the parasite can lie dormant in the liver for up to four years before making the victim sick.

Pulling the plug on a pandemic

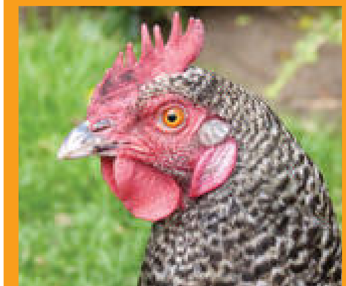
1 Vaccination
By far the most effective means of stopping disease in its tracks, however new vaccines can take six months or more to develop.

2 Education
Whether they advocate hand washing, face masks or condoms, public education efforts can dramatically cut down infection rates.

3 Reducing travel
Grounding flights and encouraging authorities to limit all forms of travel can help to put the brakes on a potential pandemic.

4 Limiting contact
Encouraging companies to call off meetings and asking people to stay at home limits exposure to pathogens.

5 Pre-outbreak monitoring
By keeping a close eye on animal diseases which could one day infect humans, scientists get to know potential future enemies.



“A significant proportion of a nucleus’s mass is made up by the strong nuclear force”

Fission vs fusion

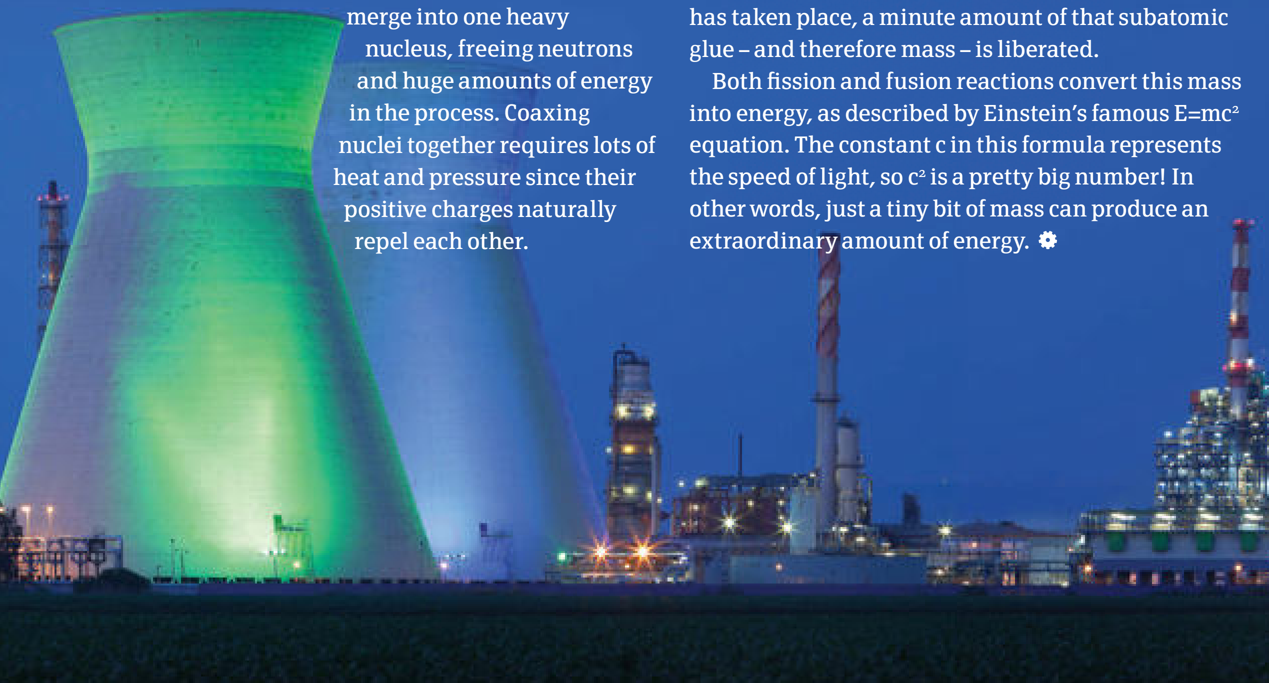
Nuclear fusion and nuclear fission battle it out to determine which is the mightiest reaction…

Nuclear fission and fusion reactions harness the strong nuclear force – the phenomenal ‘glue’ which holds atoms together. To produce a fission reaction, a neutron is fired at an atomic nucleus, smashing it apart and leaving radioactive nuclei, neutrons and energy. In a fusion reaction, two or more nuclei are combined; they merge into one heavy nucleus, freeing neutrons and huge amounts of energy in the process. Coaxing nuclei together requires lots of heat and pressure since their positive charges naturally repel each other.

So how do these reactions generate such epic amounts of energy? An atom’s mass is more than just the sum of its parts. Strangely enough, a significant proportion of a nucleus’s mass is made up by the strong nuclear force – the glue that binds it together.

So although the number of protons and neutrons is the same before and after a fission or fusion reaction has taken place, a minute amount of that subatomic glue – and therefore mass – is liberated.

Both fission and fusion reactions convert this mass into energy, as described by Einstein’s famous $E=mc^2$ equation. The constant c in this formula represents the speed of light, so c^2 is a pretty big number! In other words, just a tiny bit of mass can produce an extraordinary amount of energy.



Reaction summary

Nuclear fission

Definition: The splitting of an atom’s nucleus into smaller constituent parts

Occurrence: Rare in nature – now found most often in nuclear power stations

Conditions: You need enough fissile matter and a high-powered neutron

Products: Neutrons, radioactive nuclei and energy

Energy requirement: Small – just enough to fire neutrons at a nucleus

Energy released: Over 100 million times more energy than that released from the same mass of coal

Nuclear fusion

Definition: The joining of two or more atomic nuclei to form a single heavy nucleus

Occurrence: Takes place at the heart of stars

Conditions: Extremely high temperature and pressure

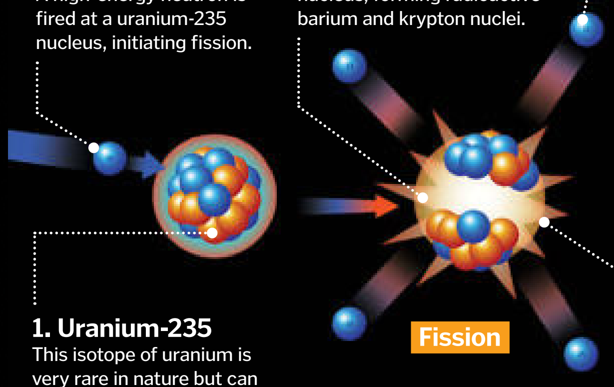
Products: Heavier nuclei, neutrons and energy

Energy requirement: Very large – enough to overcome the nuclei’s natural repulsion

Energy released: Three or four times more energy created than a fission reaction

At an atomic level…

This microscopic view of the nuclear reactions reveals how they generate energy



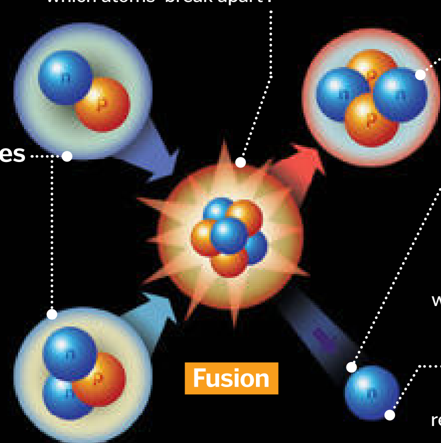
1. Uranium-235
This isotope of uranium is very rare in nature but can be produced through uranium enrichment.

2. Neutron meets uranium
A high-energy neutron is fired at a uranium-235 nucleus, initiating fission.

3. Splitting the nucleus
The reaction splits the uranium nucleus, forming radioactive barium and krypton nuclei.

4. Neutrons
Neutrons liberated by the fission reaction go on to cause other collisions, sparking a chain reaction.

5. Energy
The reaction converts a mass generated by the nuclear strong force into energy, lost as heat.



1. Hydrogen isotopes
Deuterium and tritium are isotopes of hydrogen. Deuterium is found in seawater, and tritium can be derived from lithium.

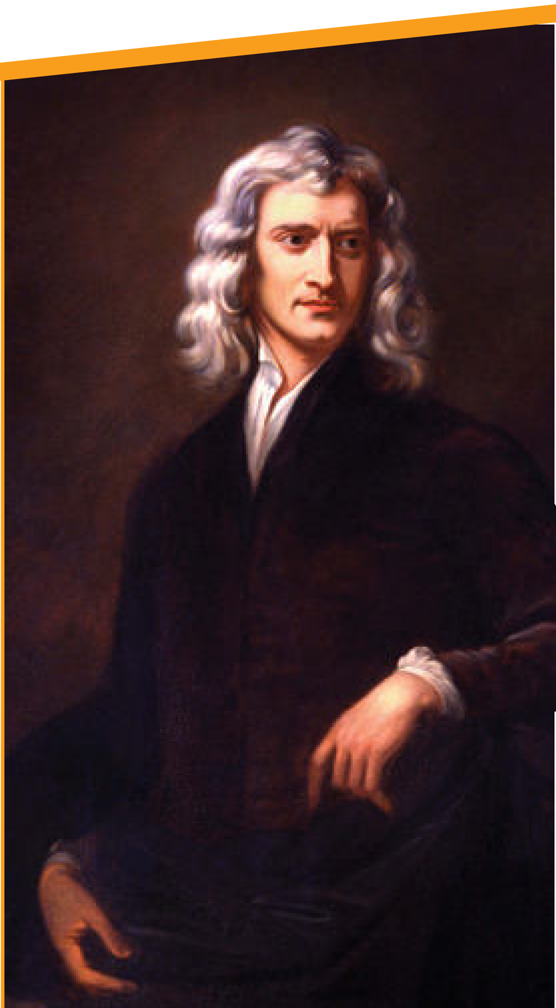
2. Heat
At temperatures exceeding 100m°C (180m°F), the fuel becomes a plasma in which atoms ‘break apart’.

3. Helium
At close proximity, the strong nuclear force takes over and binds the nuclei to form a helium nucleus.

4. Neutron
The reaction generates an incredible amount of energy, carried mostly by a neutron which comes whizzing out at high speed.

5. Self-sustaining
In order to trigger further reactions, this energy must be confined to keep the plasma hot and dense.

HEROES OF… SCIENCE
HISTORY'S MOST INFLUENTIAL SCIENTISTS



Sir Isaac Newton

Newton exploring the properties and nature of light

Often considered the father of modern-day physics, Sir Isaac Newton is one of the most influential scientists of all time

Sir Isaac Newton was an English physicist who laid down the foundations of modern-day classical mechanics. The core of this was his description of universal gravitation and clarifying the existing three laws of motion, which he brought together under one system. This achievement allowed Newton to demonstrate that the motions of celestial bodies were dictated by a single set of universal laws, radically shifting scientific thought away from heliocentrism – the idea of the Sun being at the centre of the universe – and setting the stage for Einstein's theories of general and special relativity over 200 years later.

Newton was born on 4 January 1643 in Lincolnshire, England. He attended the King's School in Grantham, Lincolnshire, from the age of 12 and later, in 1661, was admitted to Trinity College, Cambridge, in a work-study position. Cambridge at the time was still basing much of its scientific and mathematical teachings on Aristotle, however due to Newton's widespread reading of many modern thinkers, the university was slowly introducing the ideas of Descartes, Kepler and Galileo. He left Cambridge in 1665 with a degree and spent the next two years formulating his theories on calculus, optics and gravitation.

Following this work, Newton became increasingly interested in optics, with him lecturing on the subject between 1670 and 1672. It was during this period that he developed the Newtonian telescope (the world's first functional reflecting specimen), which he presented to the Royal Society alongside an investigation into the refraction of light. He proceeded to conduct much work into the nature and properties of light over the next 30 years, which would culminate in the publication of his 1704 text *Opticks*.

Prior to that, in 1687, Newton published his groundbreaking book *Philosophiae Naturalis Principia Mathematica* (ie *Mathematical Principles Of Natural Philosophy*) – which outlined his laws of motion, universal gravitation and a derivation of Johannes

The big idea

Newton's 1687 *Philosophiae Naturalis Principia Mathematica* laid out much of today's classical mechanics, but arguably its most important theory was that of universal gravitation. Newton's law states that any particle of matter in the universe attracts any other with a force varying directly as the product of the masses and inversely as the square of the distance between them. This notion drew together the logically independent laws of motion set out by Johannes Kepler decades before, which since his death had been accepted but not related to causality, and led to an accurate – even by modern standards – description of how planets, moons and comets move through space.

Newton's law has since been succeeded by Albert Einstein's theory of general relativity, which allows systems to be described with far greater accuracy – especially when they are very large.

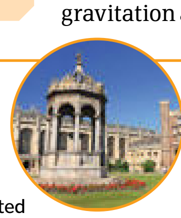
A life's work

Chart Newton's career from his early years to his death

1643
Isaac Newton is born on 4 January in Woolsthorpe Manor (right), Lincolnshire, England.

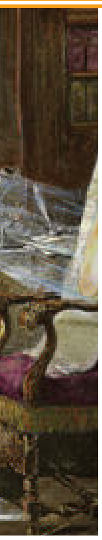
1655
Newton attends the King's School from the age of 12 to 17.

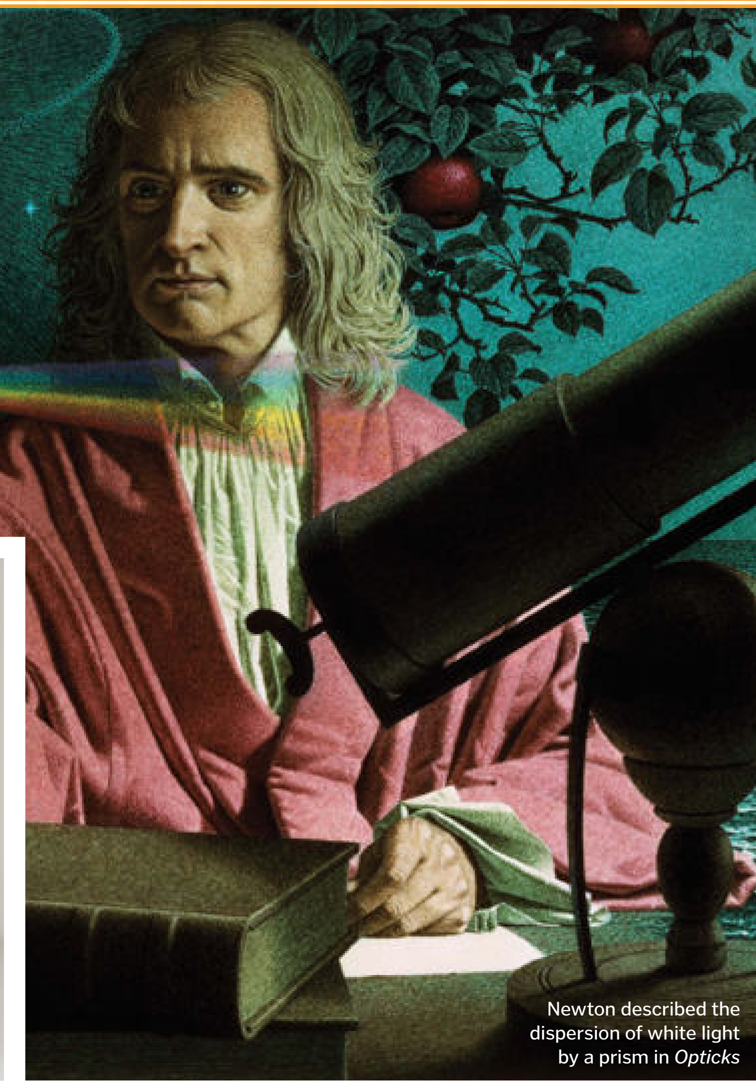
1661
He's accepted into Trinity College, Cambridge. After four years he obtains a maths degree, specialising in calculus.



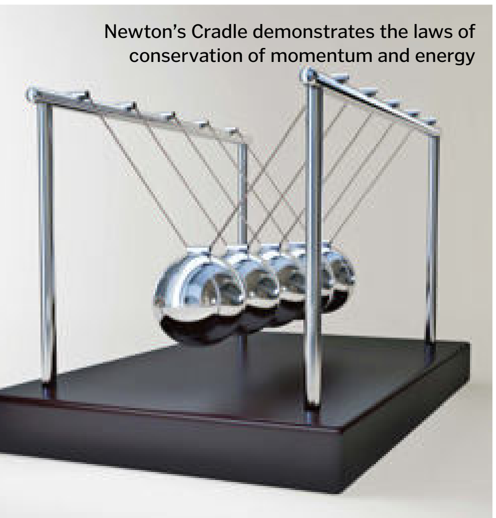
1670
Newton takes his interest in optics and astronomy to a new level by lecturing on the subjects at Cambridge.

1672
Newton builds his famous reflecting telescope (right) and presents it to the Royal Society of London.





Newton described the dispersion of white light by a prism in *Opticks*



Newton's Cradle demonstrates the laws of conservation of momentum and energy

Top 5 facts: The life and times of Sir Isaac Newton

1 Biblical
Despite Newton's great scientific achievements, he actually wrote more on biblical hermeneutics and occult studies than science. He was a lifelong, if unorthodox, Christian.

2 Knighthood
Newton was only the second scientist in history to be knighted, which he was awarded in 1705. His coat of arms was a shield with two crossed shinbones.

3 Minted
Newton was warden of the Royal Mint during the Great Recoinage of 1696. During his time at the Royal Mint he successfully prosecuted 28 forgers for creating illegal currency.

4 Apocalypse
In 1704 Newton attempted to glean scientific information from the Bible. From what he extracted from the religious text he predicted that the end of the world would come no earlier than 2060.

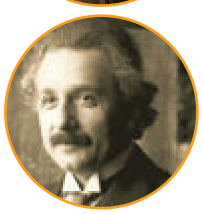
5 Mercury
After Newton's death in 1727 his hair was found to contain high levels of mercury, indicating he had suffered mercury poisoning.

Kepler's laws of planetary motion. Even though Newton's genius had been noted prior to the publication of this seminal text, its success established him within the wider scientific society. Indeed, as a result of this work, he would not only be welcomed into the Royal Society, but also knighted by Queen Anne – only the second scientist to have been awarded the title at this time. Following a wider print run and subsequent editions, Newton acquired a keen circle of admirers including Edmond Halley and Nicolas Fatio de Duillier.

In his later life Newton continued his work in mathematics, astronomy and optics, however also took up the post of warden and then master of the Royal Mint, where he oversaw a great re-coining of the nation's currency. In addition, in 1703 Newton was elected president of the Royal Society and an associate of the French Académie des Sciences. Newton died in his sleep in London on 31 March 1727.

In their footsteps…

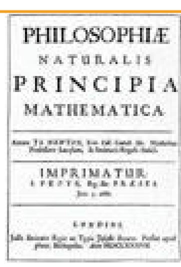
William Whiston
William Whiston was a pupil of Newton's and, following his departure, succeeded him as Lucasian Professor of Mathematics at the University of Cambridge. He is best known today for his work with Roger Cotes on comets.



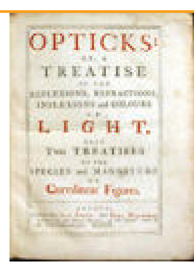
Albert Einstein
Newton's theory of universal gravitation and codification of classical mechanics formed the basis of Einstein's thinking on astrophysics, allowing him to formulate his landmark theories of general and special relativity.

> *"He developed the Newtonian telescope (the world's first functional reflecting specimen), which he presented to the Royal Society"*

1687
Newton publishes his *Philosophiae Naturalis Principia Mathematica* after years of research into gravitation and planetary motion.



1704
Newton publishes *Opticks*, which demonstrates how a prism can act as a beam expander.



1705
Newton is knighted by Queen Anne – who visits Trinity College – due to his scientific work and role as master of the Royal Mint.

1724
With old age and failing health Newton moves in with his niece and her husband at Cranbury Park, near Winchester, England.

1727
Newton dies in his sleep on 31 March. He is aged 84.

"Major organs like the heart and brain are most susceptible to CO poisoning"

Understanding albinism

Why do people with this genetic condition have paler features than most?

Albinism is a genetic condition that causes an absence of melanin in the body. This pigment colours hair, skin and eyes – as well as feathers and scales in the animal world. Because albinos don't make melanin, they can lack pigment in their hair, skin and eyes (oculocutaneous albinism), or just lack eye colour (ocular albinism). More melanin in the iris results in darker eye colour (brown/black), while less melanin results in paler irises (blue/green). Eye colour – and therefore the amount of melanin – determines how much light enters the eye. The more melanin present, the better the retina is shielded from damaging bright light. A total absence of melanin causes an albino's irises to be pink with red pupils due to light reflected by blood vessels.

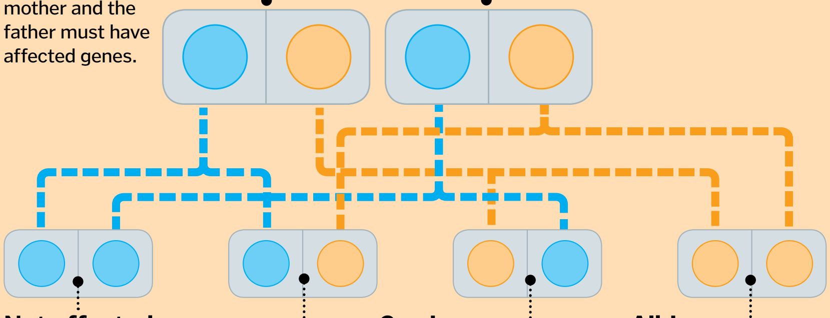
Melanin absorbs the Sun's harmful ultraviolet rays. Normally, when the skin is exposed to sunlight, more melanin is produced to absorb UV radiation and, in turn, tan the skin. Someone affected by albinism, therefore, is prone to sunburn and more susceptible to cancer so they must be careful to avoid high exposure to the Sun.

Eye colour is determined by melanin in the iris, so albinos' eyes often appear red as light rebounds off blood vessels

Recessive inheritance

Albinism is a recessive disorder, so both parents must be carriers to pass on the trait...

Parents
For a child to inherit albinism, both the mother and the father must have affected genes.



Not affected
There's a 25 per cent chance the child of two carriers will neither inherit albinism nor carry the faulty gene.

Carrier
There's a 50 per cent chance of the child being born a carrier of the affected gene but not actually becoming albino.

Albino
There's a 25 per cent chance that the baby of two carriers will be born albino and unable to produce melanin.

Why is carbon monoxide deadly?

Discover where this gas comes from and how it can kill without warning

Though you can neither see it, smell it nor taste it, carbon monoxide (CO) is an extremely poisonous gas. In fact, over 50 people die from CO poisoning each year in the UK.

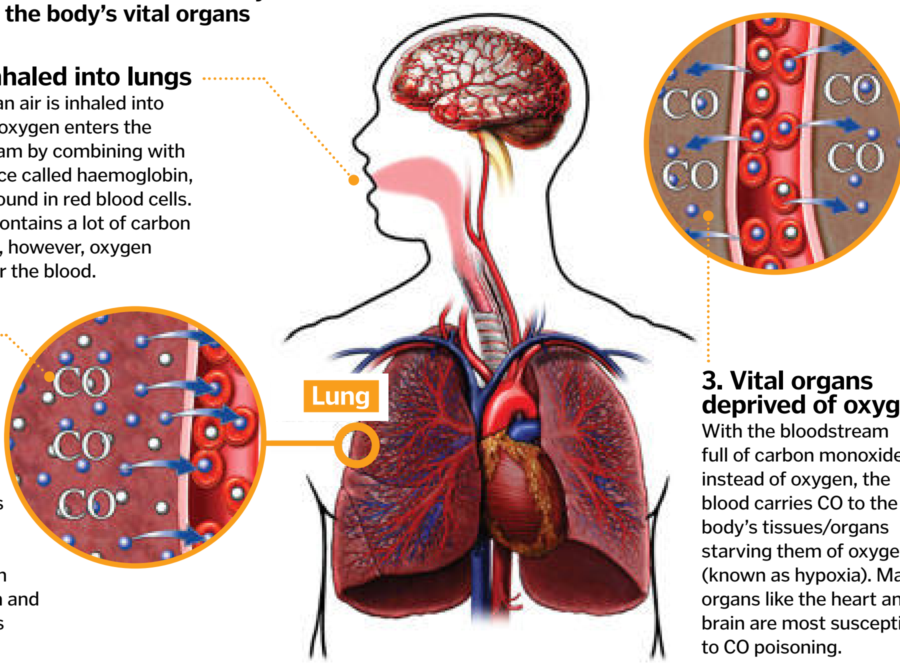
Carbon monoxide is a by-product of the incomplete combustion of carbon-based fuels, like coal. Since energy is released when a fuel reacts with oxygen, in order to perform most efficiently, a fossil fuel must have a rich air supply. When the fuel is burned with sufficient oxygen complete combustion will occur, producing carbon dioxide and water. However, when a hydrocarbon fuel is burned with only a limited air supply, incomplete combustion will occur, producing carbon (in the form of soot), water and toxic carbon monoxide gas.

Carbon monoxide poisoning

How CO can interfere with the blood's ability to deliver oxygen to the body's vital organs

1. Air inhaled into lungs
When clean air is inhaled into the lungs oxygen enters the bloodstream by combining with a substance called haemoglobin, which is found in red blood cells. If the air contains a lot of carbon monoxide, however, oxygen can't enter the blood.

2. CO displaces oxygen in blood
This happens because carbon monoxide is far better than oxygen at combining with haemoglobin, so when CO is present in the lungs the blood cells choose to absorb it over oxygen, preventing the latter from entering the bloodstream and travelling to all the body's tissues that need it.



3. Vital organs deprived of oxygen
With the bloodstream full of carbon monoxide instead of oxygen, the blood carries CO to the body's tissues/organs starving them of oxygen (known as hypoxia). Major organs like the heart and brain are most susceptible to CO poisoning.

5,000,000x

HIGHEST-RES SCOPE

In 2004 an atomic force microscope focusing on one atom distinguished features just 77 picometres across.

DID YOU KNOW? False colour is a technique used in a number of areas, including photos of space phenomena

False-colour imaging

How was this colourful closeup of a kidney stone captured by a scanning electron microscope?

What you see here is a photograph of calcium oxalate taken under high levels of microscopy: 500x magnification at 20.3 x 25.4 centimetres (8 x 10 inches), to be precise. Calcium oxalate crystals make up a large proportion of kidney stones in humans, though they are found elsewhere in nature; for instance, several plants use the needle-like crystals as part of a defence mechanism.

The scanning electron microscope (SEM) that took this image created this level of detail by moving over the kidney stone in a rectangular pattern called a raster scan, with an intensely focused beam of electrons. The electrons struck the surface of the calcium oxalate to produce a range of signals, including secondary electrons, X-rays and visible light. The position of the beam was then married up to the signal that bounced back to the microscope to reproduce that particular part of the stone in an image.

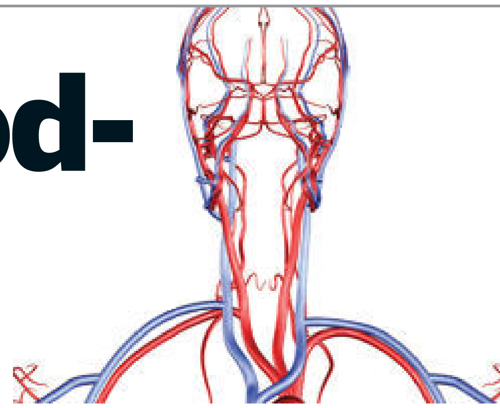
Because the spectral sensitivity of the scanning electron microscope is different to that of the spectrum visible to the human eye, false colour is applied using special software by mapping the spectral bands of the image signal to the red, green and blue equivalents of visible light. It results in the kind of spectacular shot that you see here.

Micrographs (the resulting images captured by an SEM) can reach intense levels of magnification. Not only do they have a much bigger range than light microscopes, but SEMs can actually magnify a specially prepared subject by over 500,000x. The best light microscopes, meanwhile, are restricted to about a 2,000x magnification limit. This allows scanning electron microscopes to view things as tiny as one nanometre – one-billionth of a metre – in width.

© Getty

DID YOU KNOW? Some medications can be 'hidden' within a lipid casing, which can pass across the BBB to release the drugs

What is the blood-brain barrier?



How does this gateway control the molecules that pass from the blood into the brain

The blood-brain barrier (BBB) is an essential group of cells that line the blood vessels in the central nervous system (brain and spinal cord). They allow passage of materials between the clear fluid surrounding the brain (cerebrospinal fluid) and the red blood cells in arteries, veins and capillaries. The key advantage of having such a barrier is that it prevents large micro-organisms passing into the brain and causing infections. While infections in other areas are common (such as after a cut finger, or mild chest infections), those affecting the brain are much rarer. However when they do occur (eg meningitis), they are potentially life threatening as they are very difficult to treat.

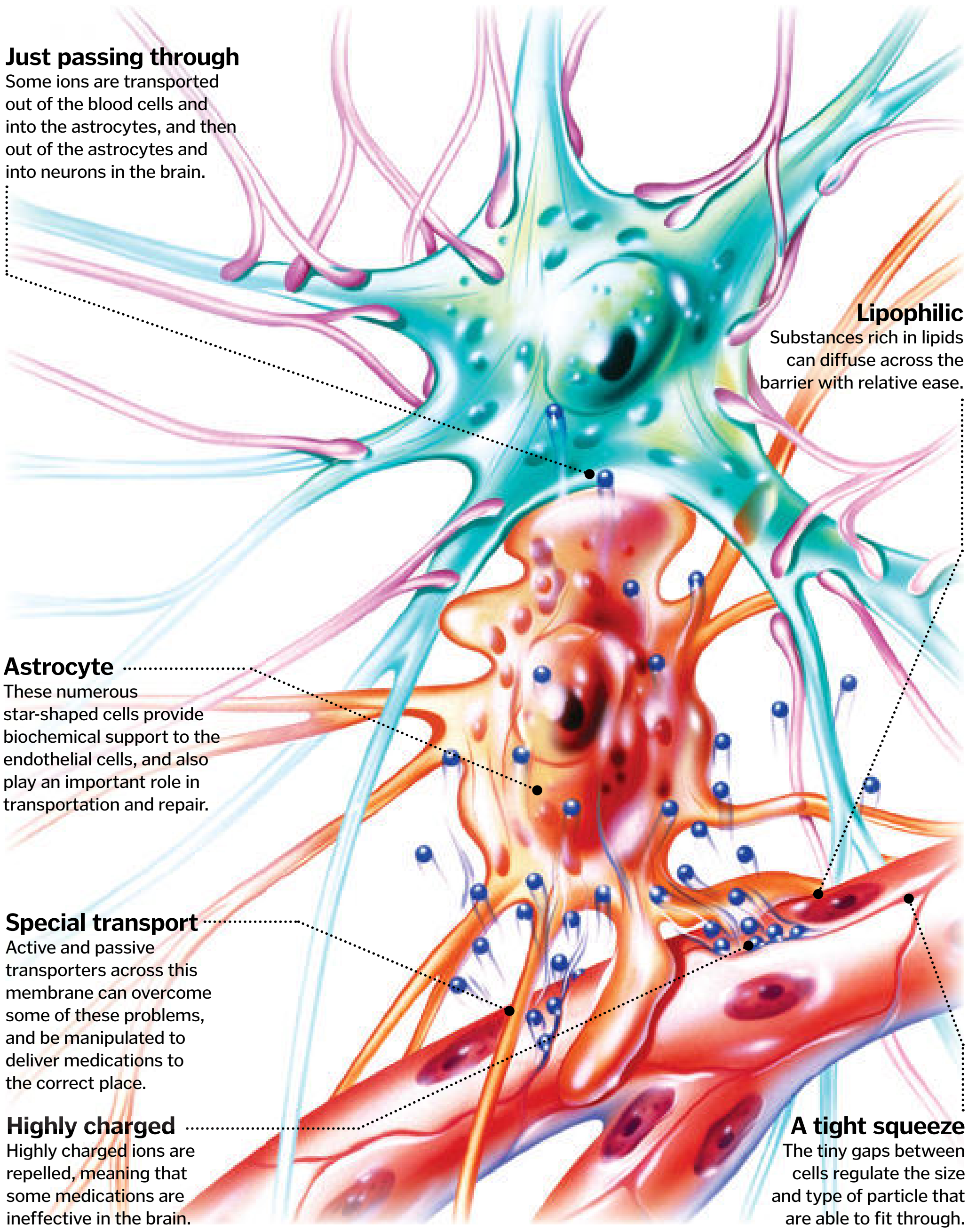
The tight junctions between cells regulate the size and type of particle that pass between them, including oxygen molecules, carbon dioxide molecules, nutrients and hormones. Since it's so effective, it also stops medications from entering the brain (such as certain antibiotics), so while they are effective in the rest of the body, they are ineffective in this vital organ. Overcoming this is a major aim of doctors in the next decade, and the battle has already started. Manipulating the blood-brain barrier's natural transport mechanisms and delivering drugs within nanoparticles to squeeze through the tight junctions are just two examples of the modern techniques that are under development.

Crossing the BBB

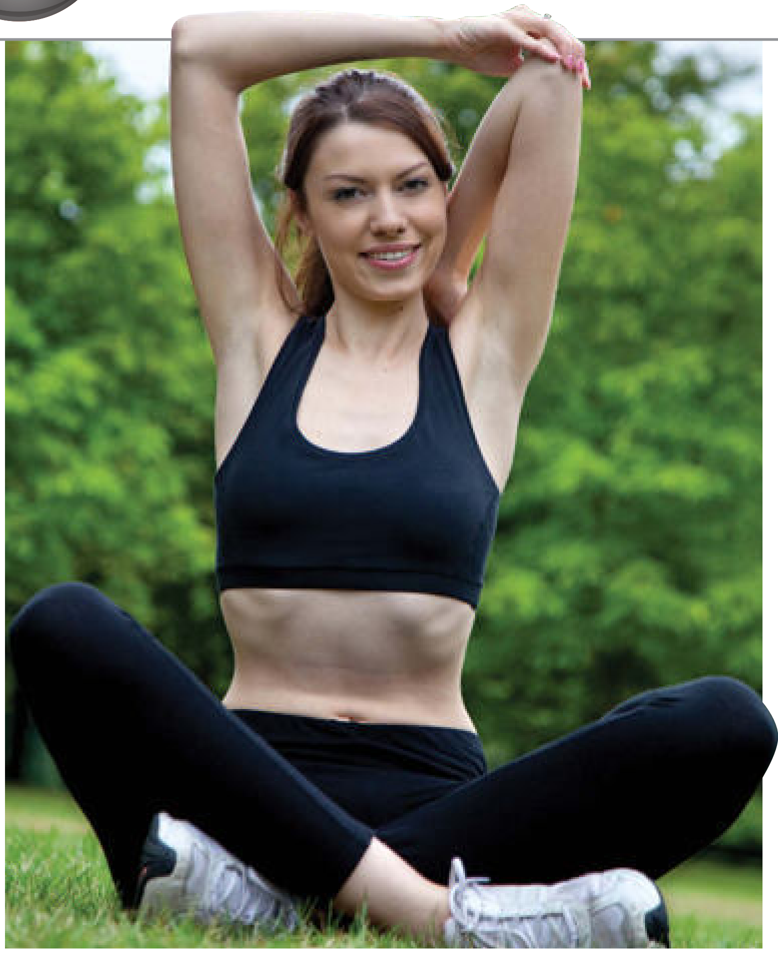
The endothelial lining of the blood-brain barrier loves lipids (fatty molecules), but it hates particles with high electrical charges (ions) and large substances. Thus the ideal substance is small, rich in lipids and has a low electrical charge. Barbiturates are such an example, as they freely flow across the blood-brain barrier to suppress brain function; they act as sedatives and antidepressants. However this free movement comes with risks – too much of it will accumulate and slow the brain to a point where you can lose consciousness and even stop breathing.

Breaking down the barrier

This built-in gateway is the main line of defence for the central nervous system



"The cage comprises 24 ribs, joining in the back to the 12 vertebrae making up the middle of the spinal column"



The human ribcage

Ribs are not merely armour for the organs inside our torsos, as we reveal here…

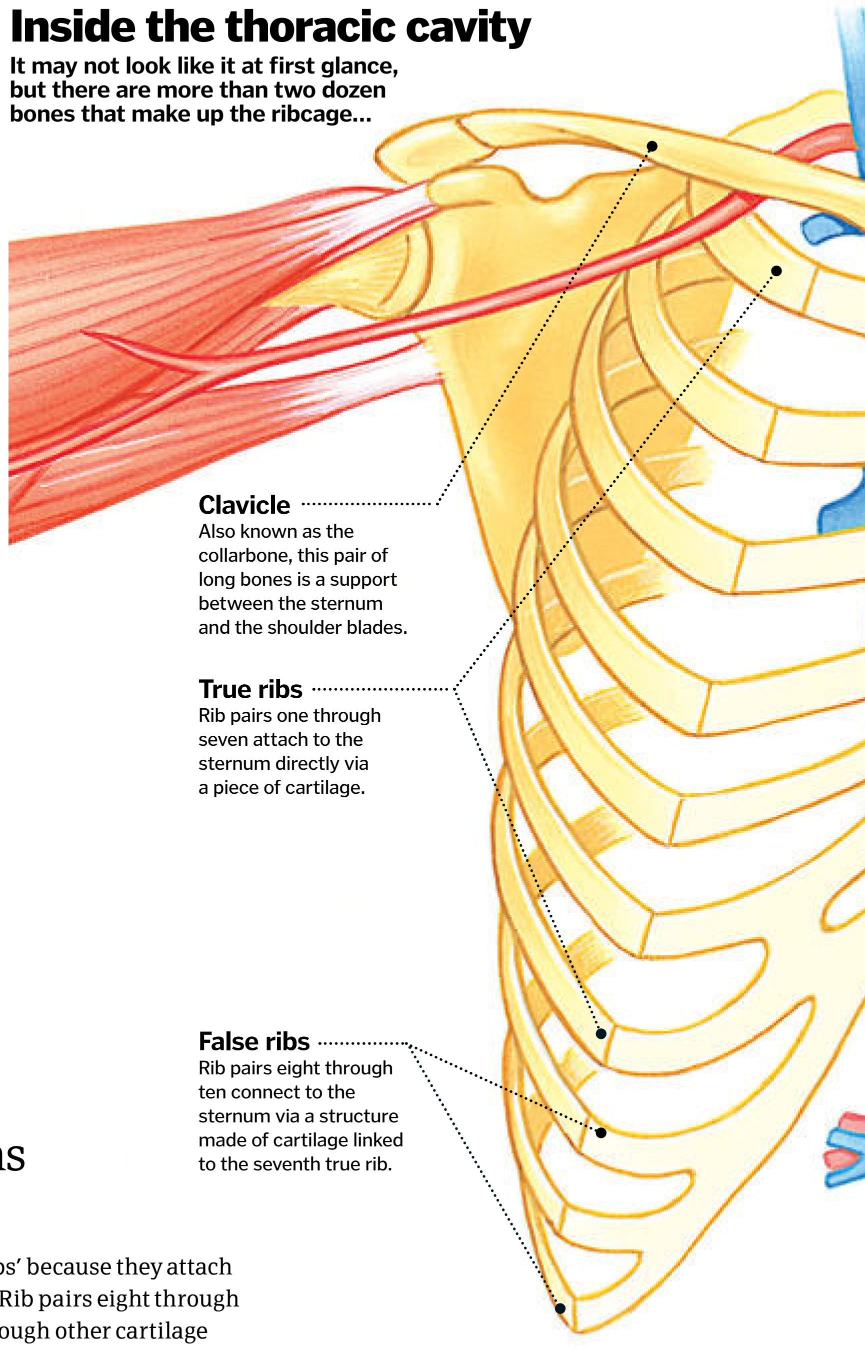
The ribcage – also known as the thoracic cage or thoracic basket – is easily thought of as just a framework protecting your lungs, heart and other major organs. Although that is one key function, the ribcage does so much more. It provides vital support as part of the skeleton and, simply put, breathing wouldn't be possible without it.

All this means that the ribcage has to be flexible. The conical structure isn't just a rigid system of bone – it's both bone and cartilage. The cage comprises 24 ribs, joining in the back to the 12 vertebrae making up the middle of the spinal column. The cartilage portions of the ribs meet in the front at the long, flat three-bone plate called the sternum (breastbone). Or rather, most of them do. Rib pairs one through seven are called 'true ribs' because they attach directly to the sternum. Rib pairs eight through ten attach indirectly through other cartilage structures, so they're referred to as 'false ribs'. The final two pairs – the 'floating ribs' – hang unattached to the sternum.

Rib fractures are a common and very painful injury, with the middle ribs the most likely ones to get broken. A fractured rib can be very dangerous, because a sharp piece could pierce the heart or lungs. There's also a condition called flail chest, in which several ribs break and detach from the cage, which can even be fatal. But otherwise there's not much you can do to mend a fractured rib other than keep it stabilised (usually by wrapping or taping), resting and giving it enough time to heal.

Inside the thoracic cavity

It may not look like it at first glance, but there are more than two dozen bones that make up the ribcage…



Clavicle
Also known as the collarbone, this pair of long bones is a support between the sternum and the shoulder blades.

True ribs
Rib pairs one through seven attach to the sternum directly via a piece of cartilage.

False ribs
Rib pairs eight through ten connect to the sternum via a structure made of cartilage linked to the seventh true rib.

What are hiccups?

Hiccupping – known medically as singultus, or synchronous diaphragmatic flutter (SDF) – is an involuntary spasm of the diaphragm that can happen for a number of reasons. Short-term causes include eating or drinking too quickly, a sudden change in body temperature or shock.

However, some researchers have suggested that hiccupping in premature babies – who tend to hiccup much more than full-term babies – is due to their underdeveloped lungs. It could be an evolutionary leftover, since hiccupping in humans is similar to the way that amphibians gulp water and air into their gills to breathe.

5 TOP FACTS
RIBCAGE TRIVIA

Flexible cage
1 In normal adults, the ribcage expands by three to five centimetres (1.2 to two inches) when you inhale. In an average breath at rest, we take in about 500 millilitres (0.9 pints) of air.

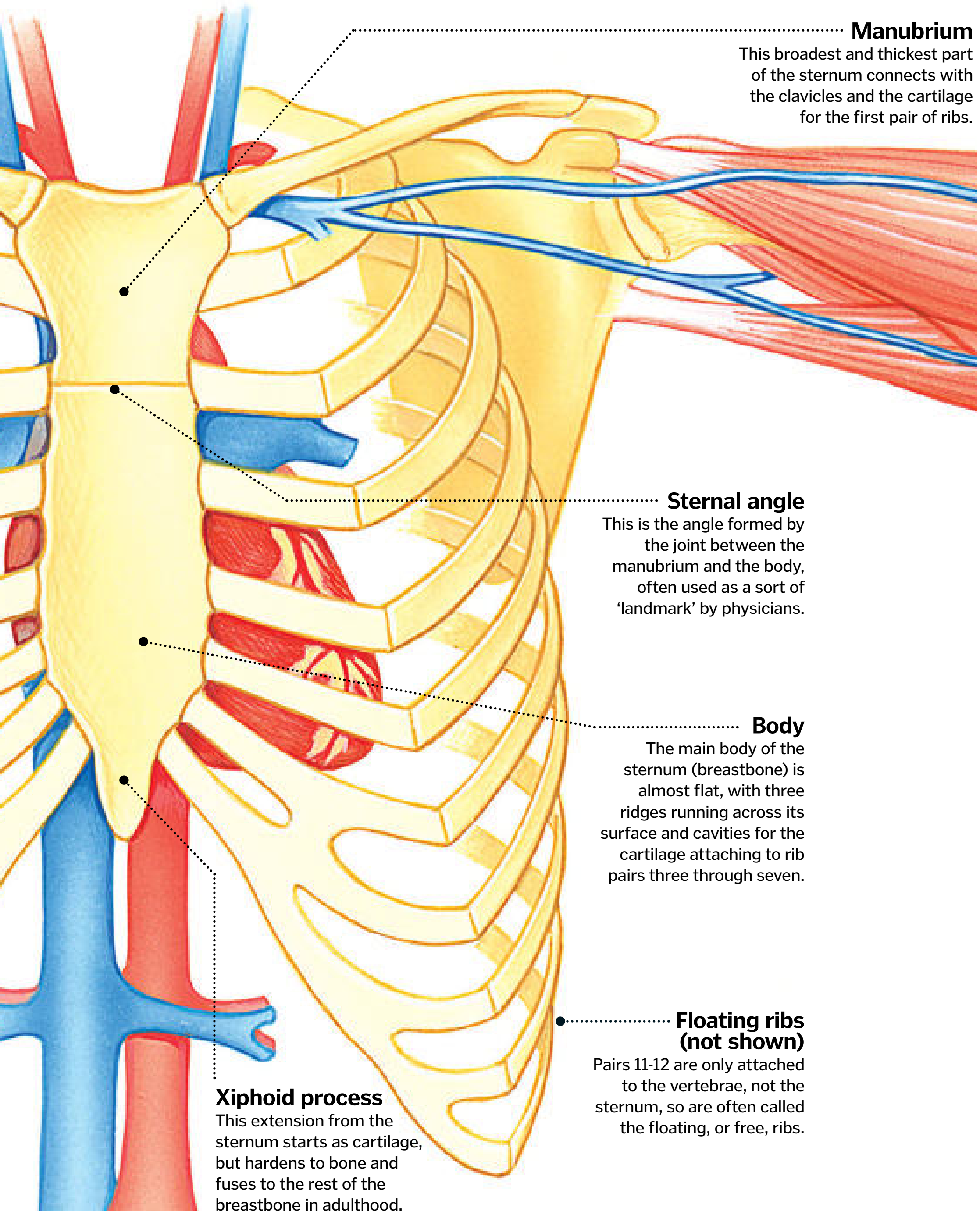
Endless ribs
2 Snakes can have up to 400 vertebrae, with all but the tail vertebrae having a pair of ribs. Each rib is attached to a belly scale which is a key part of how snakes slither around.

Fractures
3 The seventh and the tenth ribs are the ones most likely to get broken in humans, while the first pair is rarely fractured because of its shielded location behind the clavicle.

Sunken chest
4 Pectus excavatum is a congenital deformity caused by abnormal growth of the ribcage, resulting in a caved-in appearance that can also affect the heart and lungs.

Tasty ribs
5 Large carnivores, such as lions, often head towards the ribcages of their kills first to devour both the rib meat and rich organs, like the heart, which are encased within.

DID YOU KNOW? *The condition known as flail chest is fatal in almost 50 per cent of cases*



Manubrium
This broadest and thickest part of the sternum connects with the clavicles and the cartilage for the first pair of ribs.

Sternal angle
This is the angle formed by the joint between the manubrium and the body, often used as a sort of 'landmark' by physicians.

Body
The main body of the sternum (breastbone) is almost flat, with three ridges running across its surface and cavities for the cartilage attaching to rib pairs three through seven.

Floating ribs (not shown)
Pairs 11-12 are only attached to the vertebrae, not the sternum, so are often called the floating, or free, ribs.

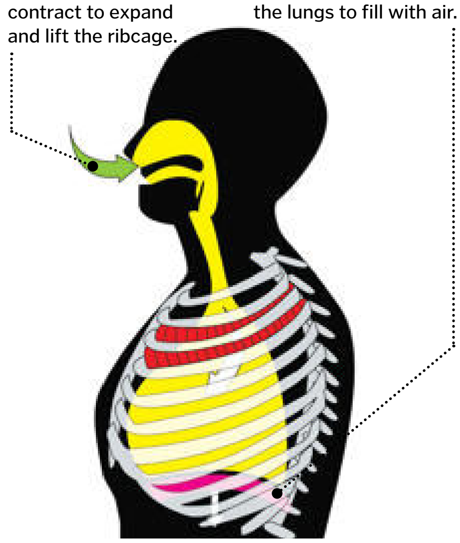
Xiphoid process
This extension from the sternum starts as cartilage, but hardens to bone and fuses to the rest of the breastbone in adulthood.

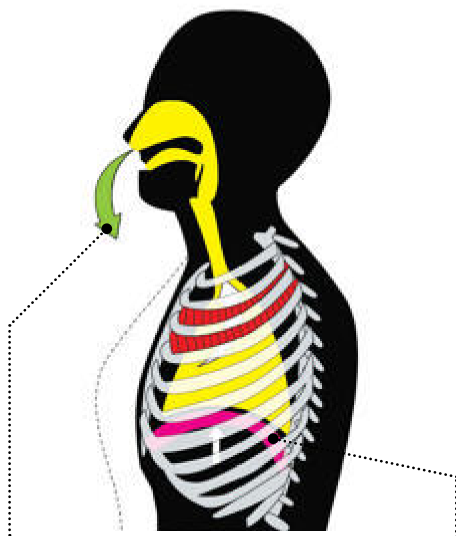
Breathe in, breathe out…

Consciously take in a breath, and think about the fact that there are ten different muscle groups working together to make it happen. The muscles that move the ribcage itself are the intercostal muscles. They are each attached to the ribs and run between them. As you inhale, the external intercostals raise the ribs and sternum so your lungs can expand, while your diaphragm lowers and flattens. The internal intercostals lower the ribcage when you exhale. This forces the lungs to compress and release air (working in tandem with seven other muscles). If you breathe out gently, it's a passive process that doesn't require much ribcage movement.

Inhalation
As you inhale, the intercostal muscles contract to expand and lift the ribcage.

Contraction
The diaphragm contracts by moving downward, allowing the lungs to fill with air.



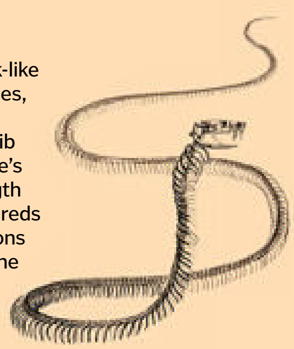


Exhalation
The intercostal muscles relax as we exhale, compressing and lowering the ribcage.

Relaxation
The diaphragm relaxes, moving upward to force air out of the lungs.

Ribs in other animals

Most vertebrates (ie animals with backbones) have a ribcage of sorts – however, ribcages can be very different depending on the creature. For example, dogs and cats have 13 pairs of ribs as opposed to our 12. Marsupials have fewer ribs than humans, and some of those are so tiny they aren't much more than knobs of bone sticking out from the vertebrae. Once you get into other vertebrates, the differences are even greater. Birds' ribs overlap one another with hook-like structures called uncinate processes, which add strength. Frogs don't have any ribs, while turtles' eight rib pairs are fused to the shell. A snake's 'ribcage', meanwhile, runs the length of its body and can comprise hundreds of pairs of ribs. Despite the variations in appearance, ribcages all serve the same basic functions for the most part: to provide support and protection to the rest of the body.



Stealth warships

We lift the lid on the latest covert vessels that are taking the art of sneaking to a whole new level

Stealth relies on five core principles when it comes to military vessels: materials, coatings, geometry, noise and tactics. While the latter is situation dependent, the first four are physical qualities that can be modified to enhance stealth with advanced technologies.

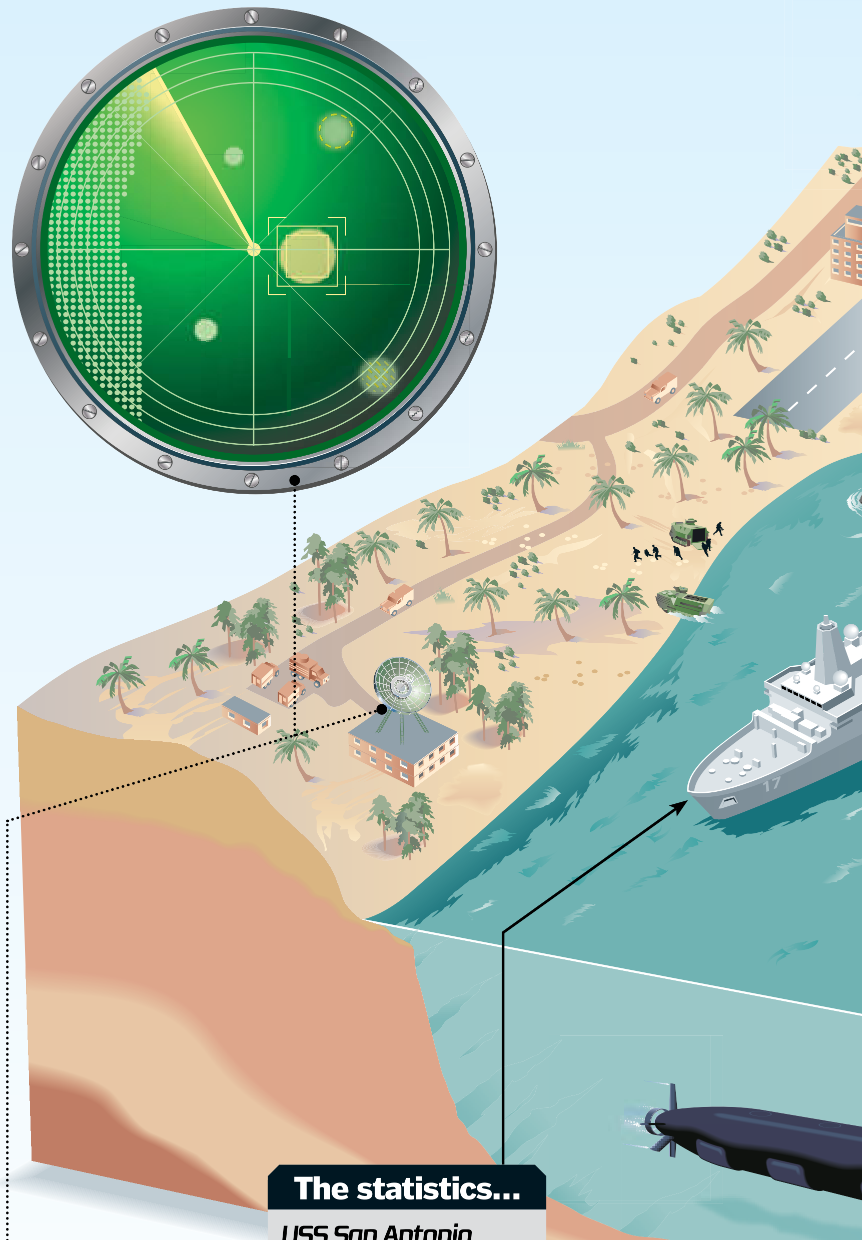
Materials are based on composites such as fibreglass rather than hard metals and the incorporation of negative-index metamaterials (NIMs). These latter artificial substances are designed to be all-but invisible to specific radar frequencies. Some vessels are also being built with demagnetisation belts – a process that involves encircling a ship with superconducting ceramic cables.

Covering a vessel with radar-absorbent coatings such as iron ball paint – tiny spheres of carbonyl iron or ferrite – can also reduce a radar cross-section. Coatings are referred to as RAMs (radar-absorbent materials) and work by transforming radar waves into heat energy. This process works as the carbonyl iron coating has an alternating magnetic field, which when hit by radar waves begins to oscillate at a molecular level, trapping the incoming signal within the material and dissipating its energy as heat.

Geometry is also crucial to remaining undetected. In terms of radar, complex structures offer a far crisper, easier-to-identify return image than those with a simple geometry. As such, modern stealth warships and submersibles are designed with this in mind, often installing protective domes over the mast and sensors, called radomes. Similarly, today's vessels have incredibly clean and angled hulls with few doors and faceted hangars.

Noise in terms of maritime vessels can come courtesy of ship wake, heat generation and operating machinery. In fluid dynamics a wake is the area of disturbed liquid flow downstream of a ship. This wake can be detected by side-scanning synthetic aperture radars (SARs), which can then work out both the ship's position and direction plus sonar installations. To combat this, the latest stealth ships are generally outfitted with low-power diesel motors with specialised heat-dissipation systems to reduce their thermal signature. Active acoustic camouflage systems beneath the hull, meanwhile, can generate a constant series of small bubbles, effectively disrupting sonar images.

In this feature **How It Works** explores four examples of cutting-edge military vessels that have been designed with covertness at the top of the priority list, from out-and-out destroyers through to agile, wraith-like submarines.



Radar
Ship positions are typically determined through the use of large-scale military radar systems on land, with data passing between them and other local vehicles and facilities. But as stealth tech advances it becomes far harder for radars to spot enemies.

The statistics...

USS San Antonio

Type: Amphibious transport dock
Roles: Troop and vehicle transport; multi-mission littoral combat
Displacement: 24,900 tons
Length: 209m (684ft)
Beam: 32m (105ft)
Draft: 7m (23ft)
Propulsion: 4 x diesel engines
Power: 31,200kW (41,600hp)
Max speed: 41km/h (25mph)

HEAD 2 HEAD

COVERT CRAFT

1. STEALTHY

Sea Shadow

Now decommissioned this was a test bed for stealth tech. Its small waterplane area twin hull (SWATH) design granted it a tiny radar cross-section.

2. STEALTHIER

Type 45

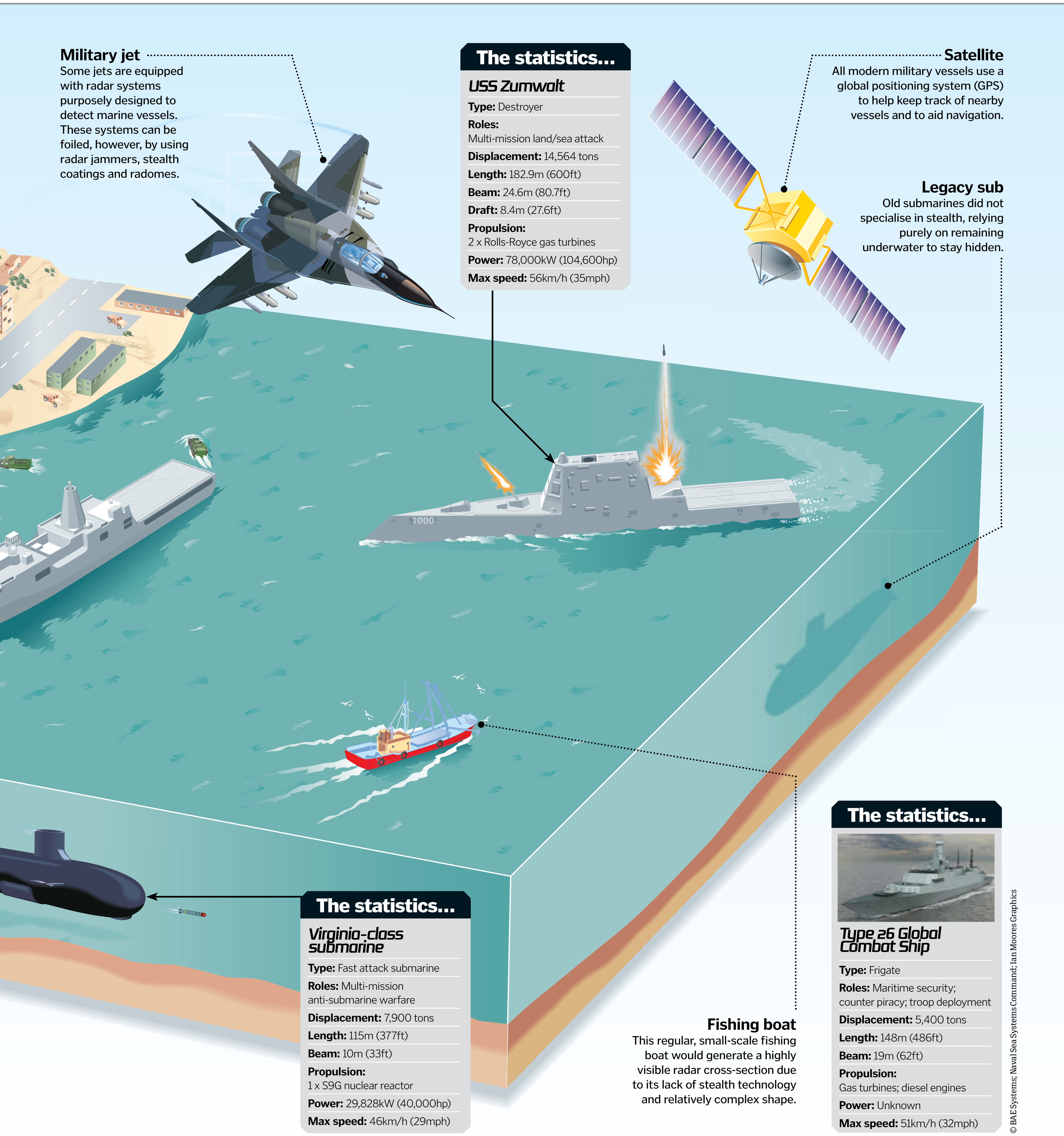
With a similarly small cross-section, but many times larger and equipped with a vast array of arms, the Type 45 destroyer is truly a cloaked titan.

3. STEALTHIEST

USS Zumwalt

Set to be the stealth king when released in 2014, its hull leaves almost no wake, it boasts low-noise propulsion and it will have electromagnetic rail guns.

DID YOU KNOW? *The Type 26 frigate has a radar cross-section smaller than a commercial fishing boat!*



Military jet

Some jets are equipped with radar systems purposely designed to detect marine vessels. These systems can be foiled, however, by using radar jammers, stealth coatings and radomes.

Satellite

All modern military vessels use a global positioning system (GPS) to help keep track of nearby vessels and to aid navigation.

Legacy sub

Old submarines did not specialise in stealth, relying purely on remaining underwater to stay hidden.

The statistics...

USS Zumwalt

Type: Destroyer

Roles: Multi-mission land/sea attack

Displacement: 14,564 tons

Length: 182.9m (600ft)

Beam: 24.6m (80.7ft)

Draft: 8.4m (27.6ft)

Propulsion: 2 x Rolls-Royce gas turbines

Power: 78,000kW (104,600hp)

Max speed: 56km/h (35mph)

The statistics...

Virginia-class submarine

Type: Fast attack submarine

Roles: Multi-mission anti-submarine warfare

Displacement: 7,900 tons

Length: 115m (377ft)

Beam: 10m (33ft)

Propulsion: 1 x S9G nuclear reactor

Power: 29,828kW (40,000hp)

Max speed: 46km/h (29mph)

Fishing boat

This regular, small-scale fishing boat would generate a highly visible radar cross-section due to its lack of stealth technology and relatively complex shape.

The statistics...

Type 26 Global Combat Ship

Type: Frigate

Roles: Maritime security; counter piracy; troop deployment

Displacement: 5,400 tons

Length: 148m (486ft)

Beam: 19m (62ft)

Propulsion: Gas turbines; diesel engines

Power: Unknown

Max speed: 51km/h (32mph)

> "Despite measuring 148 metres [486 feet] in length, the Type 26 appears as a small fishing boat on radar"

The Infiltrator

Type 26 Global Combat Ship

Capable of delivering cruise missiles, combat helicopters, unmanned hunter-killer drones and a barracks load of Royal Marines into coastal warzones, the new Type 26 Global Combat Ship being built by BAE Systems is set to deliver a platform for unprecedented covert operations while at sea. Despite weighing about 5,400 tons and measuring a whopping 148 metres (486 feet) long (that's one and a half times the size of Manchester United's football pitch), the Type 26 appears merely as a small fishing boat on radar systems. This means that when it becomes operational in 2021, it will be able to traverse the globe without detection and infiltrate the most hostile areas. The fishing boat-sized radar cross-section comes courtesy of the sleek, low-profile hull, specially angled deck panels, multi-installation radomes and advanced anti-radar/sonar damping equipment. This tech will cloak on-board vertical missile silos, an array of medium-calibre guns and a huge hangar containing both Merlin and Wildcat helicopters.

USS San Antonio

The USS San Antonio amphibious transport dock excels in its ability to efficiently carry and covertly deliver military vehicles and ground troops. This would not be so impressive if it wasn't for the size of the San Antonio, which weighs in at 25,000 tons – more than the Type 26 and USS Zumwalt combined!

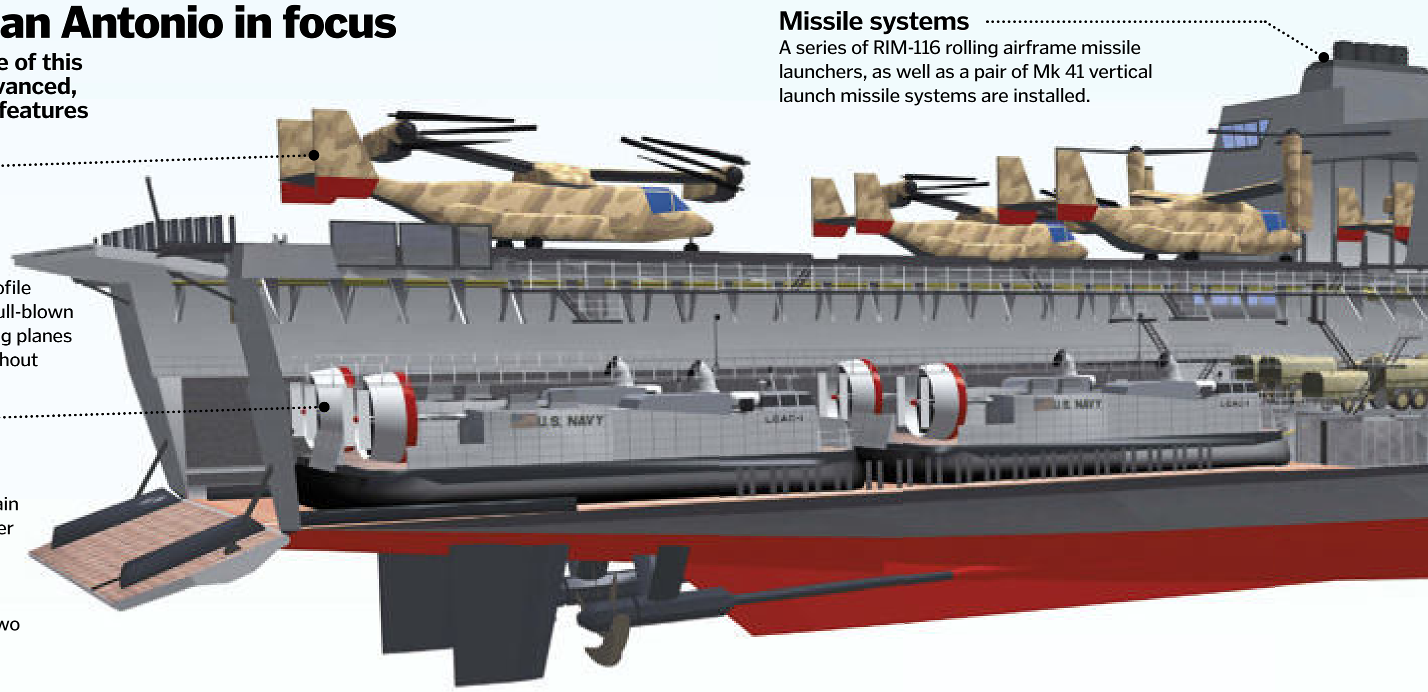
So how is such a gargantuan vessel cloaked? Well, aside from the basics, it comes down to ship-wide attention to detail. Major antennas are mounted on platforms inside two advanced enclosed mast/sensor (AEM/S) systems rather than on yardarms. Deck edges are bounded by shaped bulwarks rather than lifeline stanchions; all exterior equipment is recessed or flush-mounted; bulky things like boat-handling cranes fold down when not in use; while the anchor and anchor hold are designed to minimise radar backscatter.

This strict adherence to stealth principles transforms the radar cross-section of what is essentially a small aircraft carrier into one under half its size. This allows it to sneakily approach target coastlines and launch air-cushioned landing crafts, amphibious assault vehicles, attack helicopters, military jeeps and even armoured personnel carriers onto land along with a maximum 699 soldiers.

The Crusader

The USS San Antonio in focus

Take a look at some of this warship's most advanced, stealth-orientated features



Missile systems
A series of RIM-116 rolling airframe missile launchers, as well as a pair of Mk 41 vertical launch missile systems are installed.

Flight deck
The Antonio's exposed flight deck has a low profile compared to those on full-blown aircraft carriers, enabling planes to be stationed on it without giving away its position.

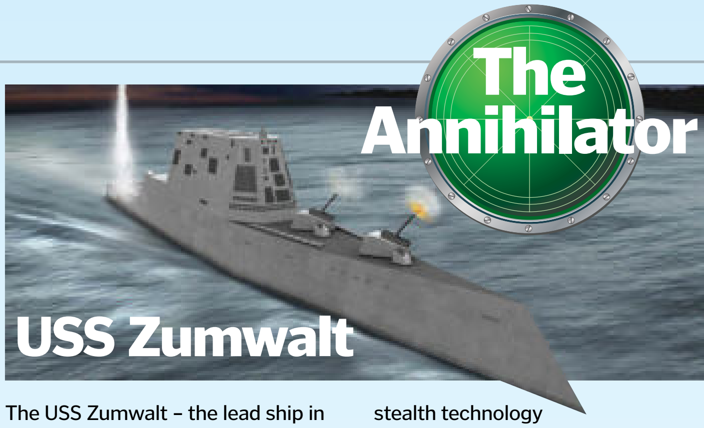
Well deck
As the San Antonio's main role is to stealthily deliver combat troops and vehicles onto coastal regions, an internal well deck is equipped with two LCAC landing crafts.

322km

STEALTHIEST RUSSIAN SUB

During Hurricane Sandy a Russian stealth submarine was detected only 322 kilometres (200 miles) from the east coast of the States – the closest any of the nation's fleet has ever come to the US mainland.

DID YOU KNOW? Sharp edges and angled flat surfaces are better at masking radar signals than rounded ones



The Annihilator

USS Zumwalt

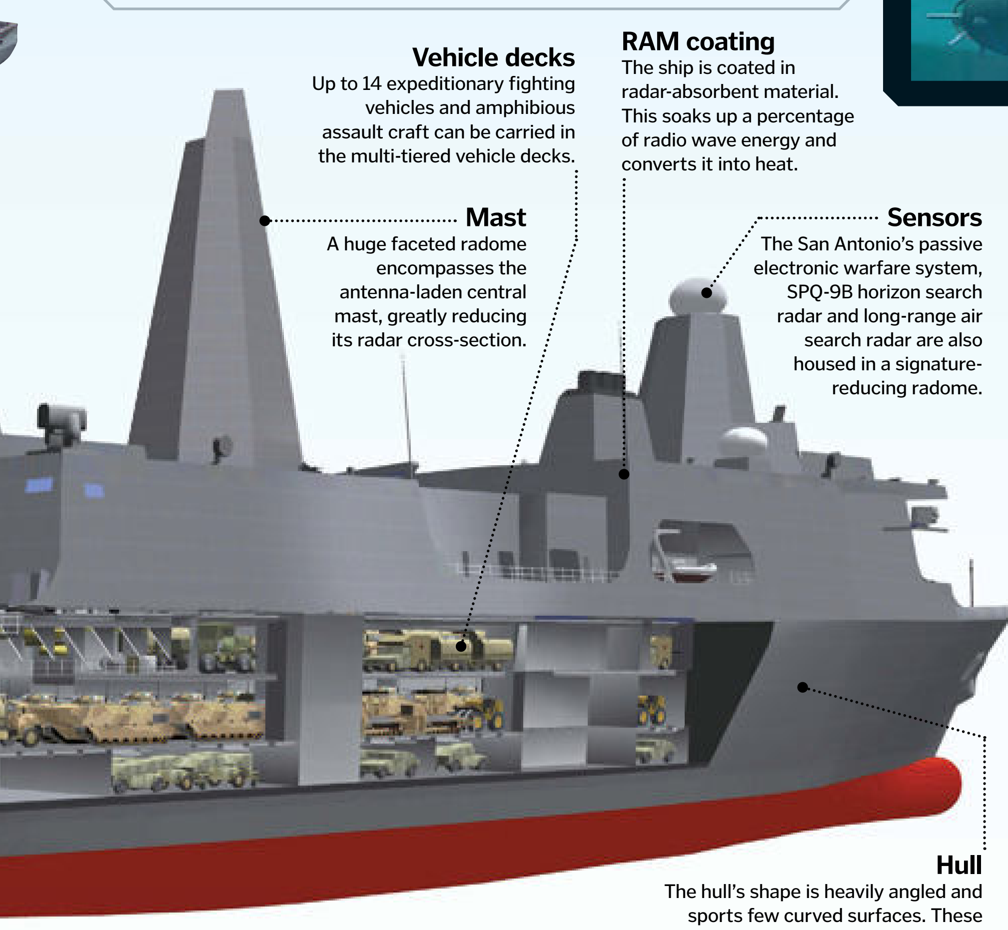
The USS Zumwalt – the lead ship in the upcoming Zumwalt-class of destroyers – doubles down on the Type 26's damage-dealing capabilities while maintaining a purist dedication to staying invisible. Stealth first. Features include an aluminium/glass-fibre composite structure, a wave-piercing hull that leaves almost no wake and an exhaust suppressor to reduce its infrared signature. On top of all this, a high-angle inward sloping exterior, noise reduction system and a trapezoidal, radome-inspired command and control centre make this near-15,000-ton titan nothing but a ghost on radar. This arsenal of stealth technology allows it to slip through the waves like a harpoon, ready to deploy an arsenal of a much more explosive nature on unsuspecting targets.

Interestingly, the Zumwalt even extends its stealth mantra to its weapons, with every gun, missile and torpedo launched by integrated computer systems. As such, far from crew members having to man gun emplacements on deck or load missiles into launchers manually – generating more noise – the Zumwalt allows the sleek, minimalist deck to remain undisturbed, so an offensive can be launched without compromising its location.

Virginia-class submarine

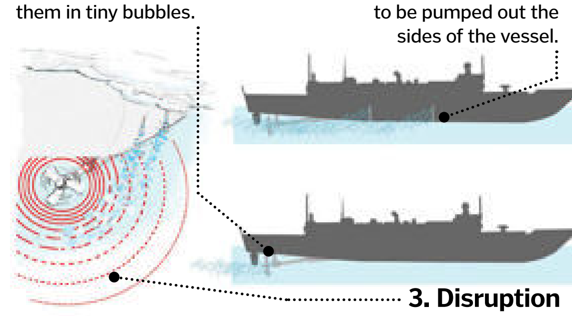
While the Type 26, USS Zumwalt and USS San Antonio are demonstrating advanced stealth technologies dedicated to reducing their cross-sections to radar, Virginia-class subs are utilising a piece of kit that can do the same for sonar. The Virginia's ultra-low acoustic signature comes courtesy of a special anechoic coating. The coating, which consists of a series of sound-absorbent, rubberised panels that sit on top of the hull work by dampening electromagnetic waves, reducing the number that bounce back and sapping their overall energy. Adding to the Virginia's stealth ability is its revolutionary pump-jet propulsion, which works by drawing water into a turbine-powered pump via an intake then pushing it out at the rear, dramatically muffling noise.

The Wraith



What are masking systems?

Masking systems in marine vehicle applications work by reducing radiated noise generated by the vessel's propulsion system and general movement. This is achieved by mounting machined perforations on the sides and propellers of the ship, through which compressed air is pumped at a high rate. This action creates a barrier of tiny air bubbles around the vessel and propellers that traps mechanical noise and disrupts sonar waves. The result of this is that enemy sonar installations, such as those found on military submarines, receive a heavily distorted image of the scanned area, with vessels commonly shrouded in a pattern akin to rain falling on the ocean surface.



"The car can withstand explosions, direct arms fire, chemical weapons and even electronic warfare"

What's inside the president's car?

The official state car of the president of the United States is no ordinary runaround…

When President Barack Obama needs to travel via road there is only one vehicle fit for the job. The presidential state car – nicknamed 'The Beast' by the US Secret Service – is that vehicle and, as its moniker would suggest, it is more like an armoured personnel carrier than a car.

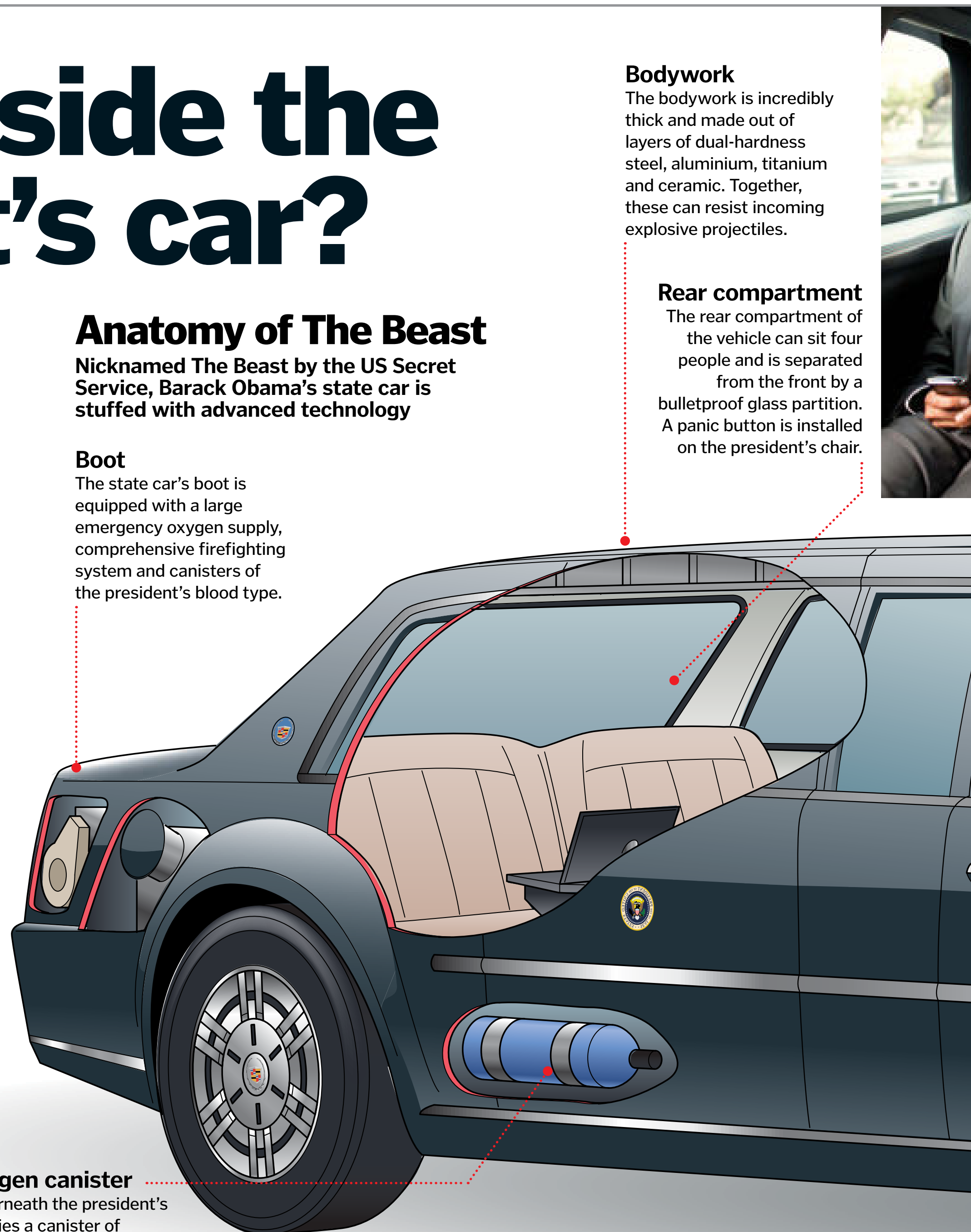
Indeed, The Beast truly is a monstrous machine, assembled by US automobile manufacturer Cadillac from a wide range of heavy-duty and performance vehicles, as well as a plethora of custom components (for a detailed breakdown see the 'Anatomy of The Beast' diagram). The scale of the vehicle's performance, resistance and feature set is immense, with the car capable of withstanding intense explosions, direct arms fire, road-laid mines, chemical weapons and even electronic warfare. Moving on to the offensive, it is outfitted with pump-action shotguns, tear gas cannons and revolutionary Kevlar-reinforced tyres – the latter capable of running on internal steel rims even if the tyres are destroyed.

The official state car is not just a piece of mobile heavy armour to protect the most important person in America, however – it is also one of the most connected places on the planet. Equipped with cutting-edge in-car Wi-Fi technology, a satellite phone, as well as direct lines to both the vice president and the Pentagon – the headquarters of the US Secret Service – no matter where the president is in the United States, events can be handled fluidly and with immediate effect.

Importantly, while the presidential state car is a mobile fortress, it is backed up on every journey by a motorcade, with a number of Secret Service-driven vehicles surrounding the car at any time. These vehicles are outfitted in a similar manner and, in partnership with agents on the ground, add another barrier between the premier and potential threat.

Anatomy of The Beast

Nicknamed The Beast by the US Secret Service, Barack Obama's state car is stuffed with advanced technology



Bodywork
The bodywork is incredibly thick and made out of layers of dual-hardness steel, aluminium, titanium and ceramic. Together, these can resist incoming explosive projectiles.

Rear compartment
The rear compartment of the vehicle can sit four people and is separated from the front by a bulletproof glass partition. A panic button is installed on the president's chair.

Boot
The state car's boot is equipped with a large emergency oxygen supply, comprehensive firefighting system and canisters of the president's blood type.

Oxygen canister
Underneath the president's seat lies a canister of oxygen in the case of a chemical weapons attack.

State car history

The first US president to ride in an automobile was William McKinley, but it wasn't until the tenure of Theodore Roosevelt that the government officially operated a state-owned presidential vehicle. Roosevelt used a Stanley Steamer, while his successor William Taft rode in a White Motor Company Model M Steamer. While these early-20th-century presidents did ride in cars, it was not until 1921 – with the ascension of Warren Harding – that a car was used in an inauguration ceremony; Harding's car was a Packard Twin Six. Since then a variety of vehicles have been used to carry the US premier, including a Lincoln V12 convertible, a Cadillac 341A Town Sedan – confiscated off Al Capone, a Lincoln Cosmopolitan and Continental – the latter the model that John F Kennedy was assassinated in, a Chrysler Imperial LeBaron, Cadillac Fleetwood Brougham and Cadillac Deville, among others.

President William Howard Taft's Model M Steamer in 1909

THE STATS
CADILLAC ONE

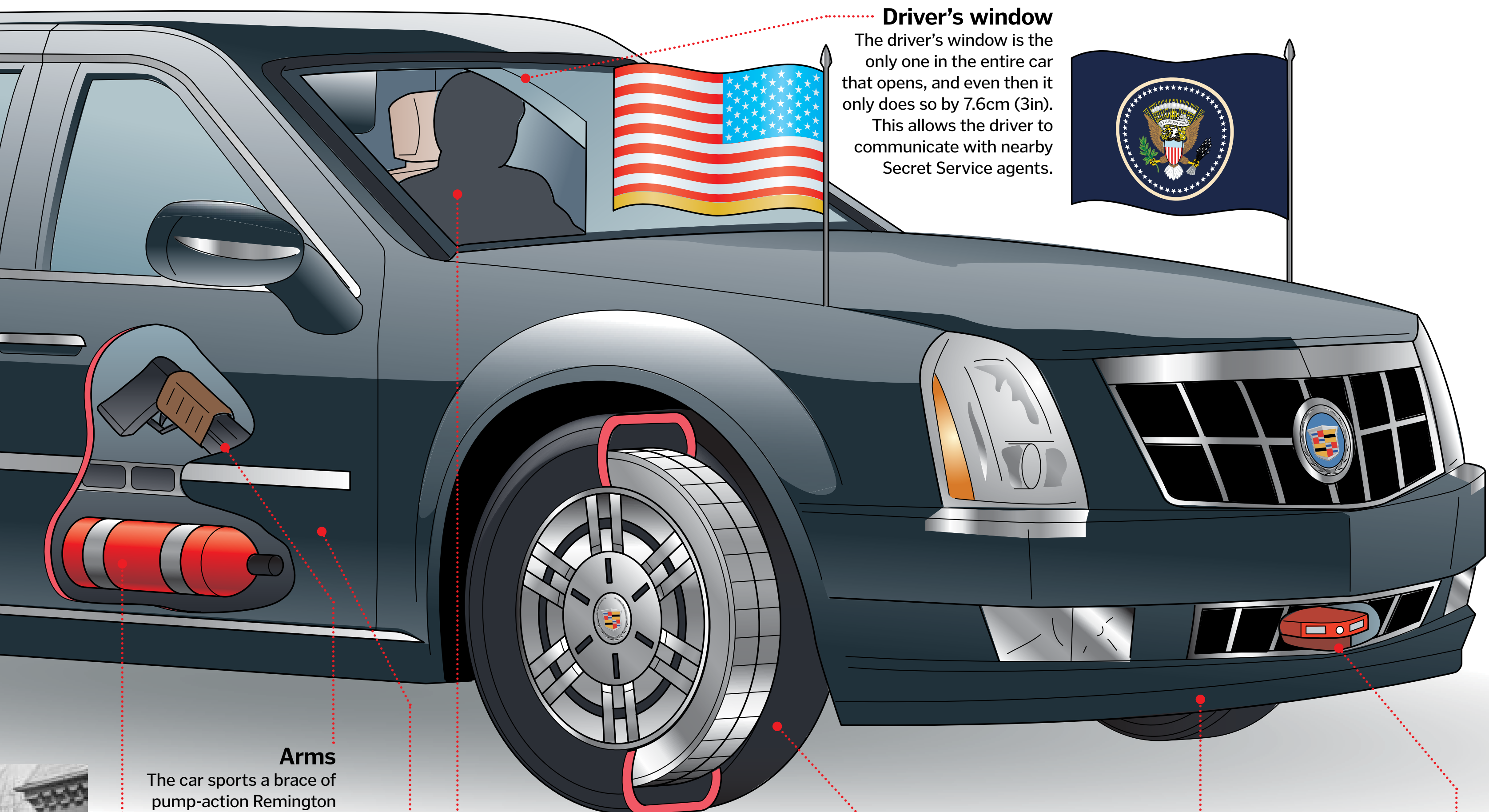
LENGTH 5.4m FUEL CONSUMPTION 3.4km/l ENGINE CAPACITY 6.5l

MAX SPEED 96km/h 0-96KM/H 15 seconds HEIGHT 1.77m

DID YOU KNOW? *The latest presidential state car – Cadillac One – entered service in 2009*

President Obama and Vice President Joe Biden travelling in the presidential state car

Each Cadillac One is reported to cost £188,800 ($300,000)



Driver's window
The driver's window is the only one in the entire car that opens, and even then it only does so by 7.6cm (3in). This allows the driver to communicate with nearby Secret Service agents.

Arms
The car sports a brace of pump-action Remington shotguns and several tear gas cannons.

Fire extinguisher
As you might expect, the Beast is equipped with a pair of high-pressure fire extinguishers.

Door
Each door weighs as much as a cabin door taken from a Boeing 757 jet due to 20.3cm (8in)-thick armour plates. The glass is bulletproof and bomb resistant too.

Driver's compartment
The driver's dashboard contains a state-of-the-art communications centre equipped with a cutting-edge GPS tracking system.

Tyre
The Beast's tyres are Kevlar reinforced, shred and puncture resistant and have steel rims underneath – the latter allowing the car to run even if the tyres are compromised.

Chassis
To combat mines, a reinforced 12.7cm (5in) steel plate runs under the car for added protection.

Electronics
The car has built-in Wi-Fi, a satellite phone, direct lines to the vice president and Pentagon as well as a host of night-vision cameras.

"The arena's distinctive shape, like a Pringle crisp, also helps the riders stay upright"

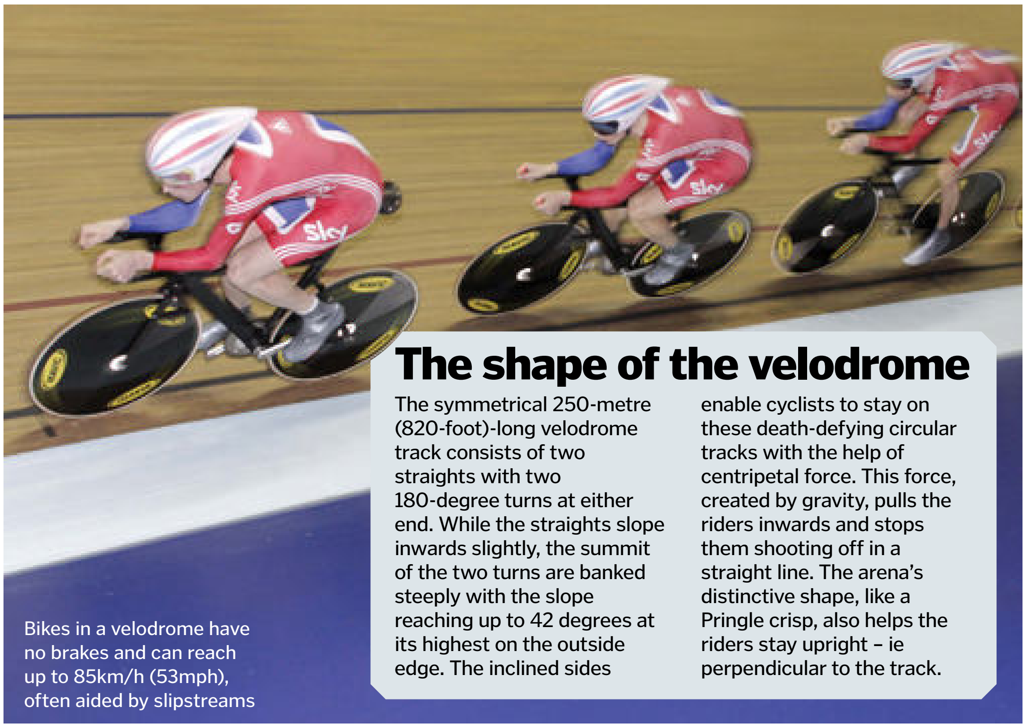
How do slipstreams work?

Why travelling directly behind another cyclist helps conserve energy in the velodrome

Slipstreaming is a technique used, especially by cyclists, to take advantage of the airflow around fast-moving objects in an effort to reduce drag. As a high-speed vehicle travels forwards it encounters air resistance, or drag, which works against the direction of travel.

Cyclists racing in a velodrome travel as fast as possible, but the faster the bike goes the greater the drag. To combat this, two or more cyclists can slipstream, or draft. It all comes down to aerodynamics of an object through a fluid (note: gases, like air, are referred to as fluids).

The lead cyclist in a race pushes through the air ahead of them, which diverts the air stream around the sides of the bike. This disturbance in the airflow creates turbulence and a pocket of reduced or negative air pressure in the wake of the bicycle. This area of lower pressure (a partial vacuum) is the slipstream and a cyclist pedalling in this region requires less effort as they encounter less drag, and in some cases they will even experience forward suction.



Bikes in a velodrome have no brakes and can reach up to 85km/h (53mph), often aided by slipstreams

The shape of the velodrome

The symmetrical 250-metre (820-foot)-long velodrome track consists of two straights with two 180-degree turns at either end. While the straights slope inwards slightly, the summit of the two turns are banked steeply with the slope reaching up to 42 degrees at its highest on the outside edge. The inclined sides enable cyclists to stay on these death-defying circular tracks with the help of centripetal force. This force, created by gravity, pulls the riders inwards and stops them shooting off in a straight line. The arena's distinctive shape, like a Pringle crisp, also helps the riders stay upright – ie perpendicular to the track.

The parts of a windsurfing board

This simple-looking watercraft comprises far more components than you might have first thought

Footstrap/harness
While nylon footstraps keep the surfer's feet attached to the board in rough seas, a harness line attaches the boom to an elasticated belt round the surfer's waist for the best stance on the board.

Board
Today's boards are between 2.5-4m (8-12.5ft) in length and can weigh up to 18kg (40lb). The board is usually made of buoyant plastic or fibreglass-covered foam.

Fins
On the underside are fins for board stabilisation. The longer the fin the more difficult the board is to handle. Longer boards also have a small retractable vertical keel called the centreboard to stop the craft veering sideways.

Wishbone boom
One end of this metal or carbon spar attaches to the mast and the other to the clew (a loop) on the back. It supports the sail and helps the boarder to balance.

Sail
The sail is made of clear polyester film (monofilm) and a polyester weave (Dacron); it fills with wind to propel the board.

Mast foot
An articulated mast foot connects the board and the mast – it allows for both back-and-forth and side-to-side motion.

"Lighter armour than their military equivalent gives ARVs greater speed and agility"

The Pit-Bull VX up close

Fast, agile and bulletproof, this armoured response vehicle is one of a new breed of robust police cars that are stopping criminals in their tracks

The Pit-Bull VX is an armoured response vehicle (ARV). Designed specifically for SWAT teams, ARVs offer protection against small arms fire, but without the heavy armour that military vehicles require for protection against cannon fire and anti-tank weapons.

Lighter armour than their military equivalent gives ARVs greater speed and agility. This makes them suitable as first-response vehicles in an emergency situation. Once at a hostile scene an ARV's tough shell means it can be used tactically as a firing post, for dropping an assault team into position or for rescuing hostages.

In the past police teams have tended to use either commercial pick-up trucks or vans. These provide a reasonably fast response time, however offer little more than the means of getting them to a hostile scene. Some SWAT teams have started to drive military vehicles, but due to their weight and lack of mobility they are not designed to be the first responders to an emergency.

ARVs like the Pit-Bull offer a compromise between the speed of an unarmoured vehicle and the protection of an armoured one. As well as offering its eight-officer crew protection against small arms fire, the Pit-Bull is grenade-proof, while firing ports enable the police to use their weapons from within. A PA system and remote-control floodlights mean they can also communicate with the assailants and illuminate an area without having to step out of the vehicle. To cap it all, if negotiations do break down, the 7.5-ton Pit-Bull VX's front bumper has been specially designed to be used as a battering ram.

Inside the mobile fort

Every effort has been taken to make the Pit-Bull VX invincible – learn how here…


The Pit-Bull VX is designed to cope with high-powered rifles, grenades and even mines

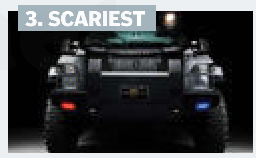
1. OLDEST

Simms Motor War Car
Built in 1902 by Vickers & Maxim the first armoured car had a top speed of just 14.5km/h (9mph) so wasn't ideal for emergencies!

2. MOST EXCLUSIVE

Cadillac One
The US president's official 'ride', Cadillac One is massively armoured. It has no roof hatches, but it does carry a supply of Barack Obama's blood.

3. SCARIEST



Pit-Bull VX
No blood here, but unlike Cadillac One – which is designed to look discreet – this armoured response vehicle is made to look as intimidating as possible.

DID YOU KNOW? WWI was the first conflict in which armoured cars were deployed – mainly in desert environments

Making an armoured Pit-Bull

The Pit-Bull VX starts life as a Ford F-550. A heavy-duty, four-wheel-drive pick-up truck, it's a workhorse of the US construction industry. The 6.7-litre V6 engine and transmission of the F-550 and chassis remain in the Pit-Bull VX. However, everything else is armoured or purpose built.

The fuel tank, battery and exhaust pipe are fitted with steel armour plating and the suspension is also strengthened. Tubeless run-flat tyres are installed, which function at speeds of up to 48 kilometres (30 miles) per hour when punctured.

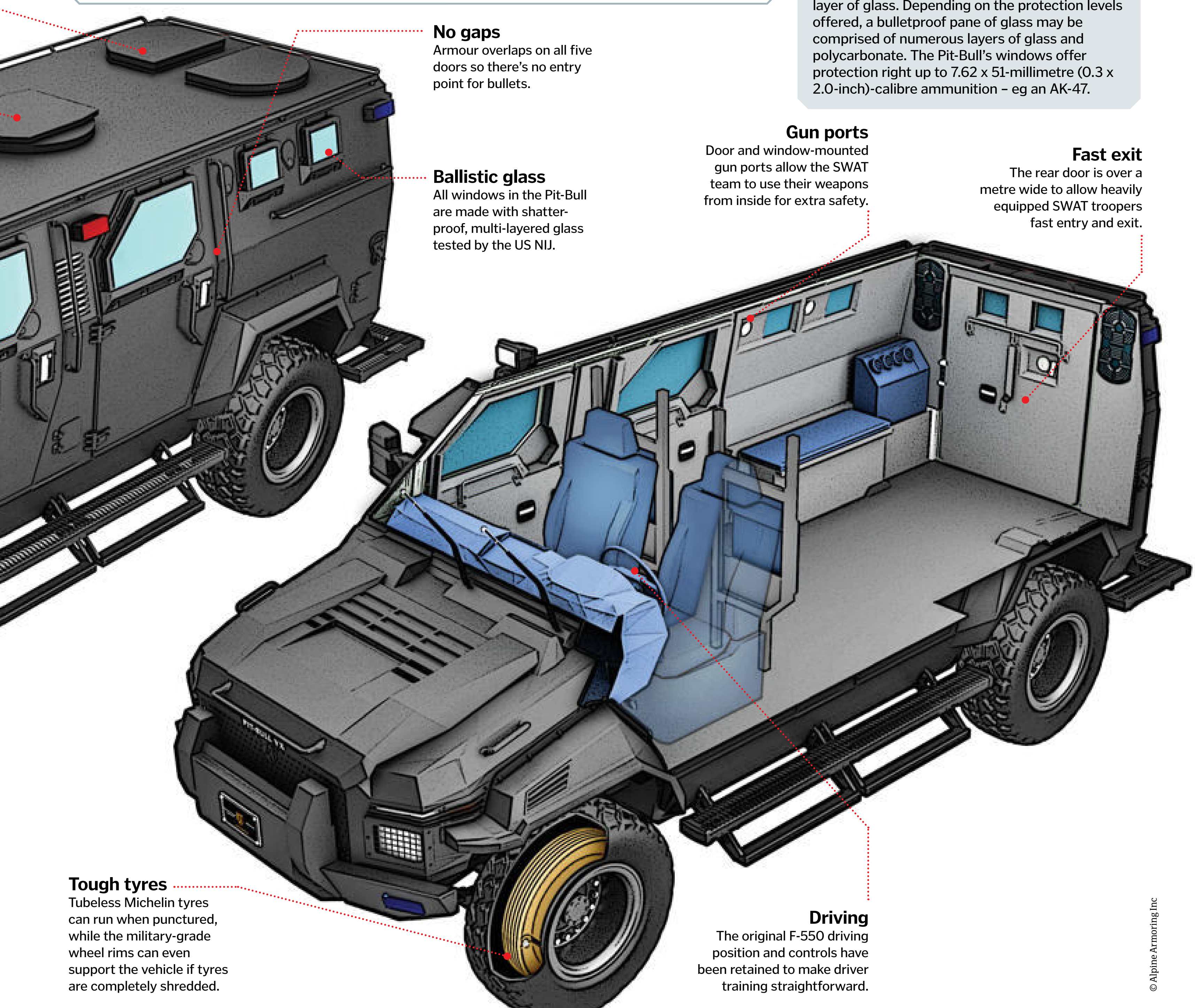
In the event of the tyres being shredded the Pit-Bull VX can still operate on its military-grade wheel rims. Ballistic steel plate is used to provide a mine and grenade-resistant floor, while the main body is made up of overlapping armour plating.

This is built and tested to US National Institute of Justice (NIJ) standards. Despite the armour, the overall weight of the Pit-Bull is 1,000 kilograms (2,200 pounds) less than the F-550 maximum operating limit – plus it still manages to maintain the same speed and performance.

Bulletproof glass

A bulletproof windscreen and windows mean the Pit-Bull VX crew have excellent visibility yet are still protected if they come under fire. Modern bulletproof, or ballistic, glass is constructed in the same way as laminated windscreens. Thin layers of polycarbonate – a transparent plastic – are glued between sheets of glass. The outer layer of glass is often softer so it will flex with the impact of a shot rather than shatter.

A bullet would pierce the outer sheet of glass, but the polycarbonate absorbs the bullet's energy, stopping it from penetrating the inner layer of glass. Depending on the protection levels offered, a bulletproof pane of glass may be comprised of numerous layers of glass and polycarbonate. The Pit-Bull's windows offer protection right up to 7.62 x 51-millimetre (0.3 x 2.0-inch)-calibre ammunition – eg an AK-47.



Recycling

What kind of machinery do we use to take our everyday rubbish and make new products out of it?

Take a look around you. Practically everything that you see which is man-made can be recycled. Everything from this copy of **How It Works** you're holding, the wooden table you're sitting at, the fabric of the clothes you're wearing, the battery in your mobile phone, the components of your computer and even the materials that make up the building around you… But not everything is recycled – why is that?

What can and can't be recycled is quite an expansive question but for domestic purposes, it depends very much on the recycling facilities available to your local authorities. Materials like paper and plastics – as long as they aren't too contaminated – can be processed and baled into a raw material ready for reuse. Metals – especially more valuable ones like lead, copper and aluminium – are highly sought after. All these materials have unique recycling processes that have been an established part of manufacturing for over a century, with scrap metal merchants and salvage yards forming a significant industry all of their own.

Many scrap electronics can be stripped down to make new products too. Car parts can be salvaged and gold can even be extracted from computer chips. For some materials, such as mercury, heavy metals like lithium and electrolytes in batteries, recycling might not make financial sense, but because of their toxic nature, recycling them is a legal requirement.

In this feature, **How It Works** checks out the specialised machinery and processes that take our daily refuse and turns it back into products that we can use again and again.

KEY DATES
RECYCLING HISTORY

400 BCE Recycling metal is very common in ancient times with weapons and coins melted down for reuse.

1939 Recycling became vital during World War II when manufactured goods were scarce.

1950 After the war, landfill sites and disposable packaging drastically increase in popularity.

1977 The first bottle banks appear in the UK as recycling becomes popular once again.

1990 The EU passes the Environmental Protection Act, making many recycling initiatives mandatory.

DID YOU KNOW? *Most batteries can be recycled, including lithium/zinc rechargeable batteries and those from a car*

Aluminium recycling

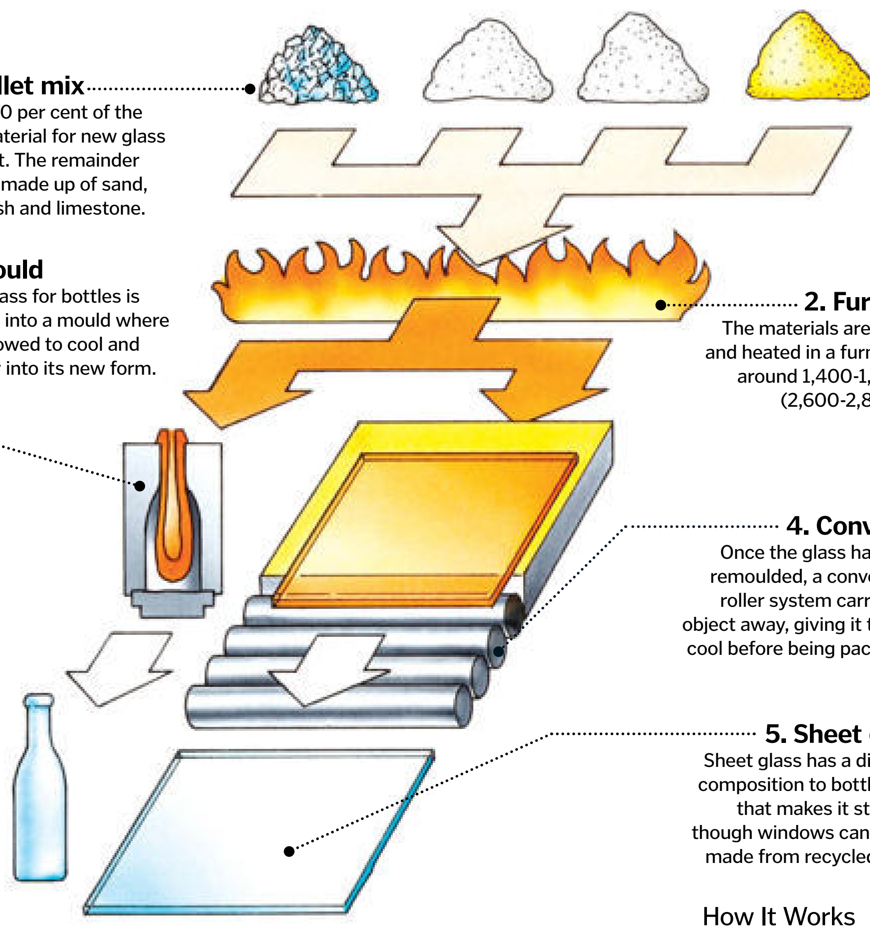
Aluminium in particular is highly sought after as a scrap metal. Because it is both lightweight and strong, it's used everywhere from drinks cans to aeroplanes. Extracting aluminium from its ore, bauxite, is relatively expensive, but salvaging it from scrap uses just five per cent of the energy needed to make new aluminium.

Like plastic bottles, a large percentage of recycled aluminium comes from beverage containers. The process is similar to plastics too. Once collected, they're separated from the other metals by an eddy current separator that splits the non-ferrous aluminium with a powerful magnet. The aluminium is shredded into pieces of uniform size, mechanically cleaned then pressed into blocks to minimise oxidation. The blocks are loaded into a furnace and heated to around 750 degrees Celsius (1,380 degrees Fahrenheit), at which point it becomes molten. The melted-down aluminium produces a surface scum known in the industry as dross, which is removed, before high-purity aluminium is added to bring the molten aluminium up to the required grade. The furnace is then rolled onto its side and the liquid aluminium poured out. The end product is either atomised aluminium powder or ingots. Because aluminium isn't transmuted by this process, it's just as good as the new stuff and can be recycled indefinitely.

Once old aluminium has been processed, it can be melted down to make new products time and again

Glass recycling

Glass recycling is an old industry that has evolved over decades. A large proportion of glass still makes up household and industrial waste, most of it bottles and glassware. Glass from bottle banks and household recycling is collected and taken to a cullet processing plant. Manual sorting separates metal and plastic contaminants as well as the various glass colours: chemicals used for different coloured glass can't be removed. The glass is washed and often passed through a ferrous metal removal machine to capture any metal contaminants that could damage machinery and taint the quality of the final product. The glass is next passed through a belt crusher that pulverises it to a uniform grade. The material is now known as cullet and is ready to be made into new products (see below).



1. Cullet mix
Up to 70 per cent of the raw material for new glass is cullet. The remainder can be made up of sand, soda ash and limestone.

2. Furnace
The materials are mixed and heated in a furnace at around 1,400-1,540°C (2,600-2,800°F).

3. Mould
Melt glass for bottles is poured into a mould where it is allowed to cool and solidify into its new form.

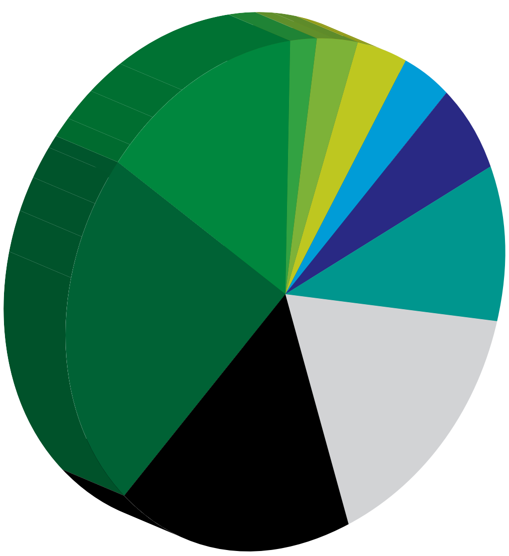
4. Conveyor
Once the glass has been remoulded, a conveyor or roller system carries the object away, giving it time to cool before being packaged.

5. Sheet glass
Sheet glass has a different composition to bottle glass that makes it stronger, though windows can still be made from recycled glass.

© Thinkstock

UK refuse breakdown

HIW reveals the various materials which make up annual household waste in Britain



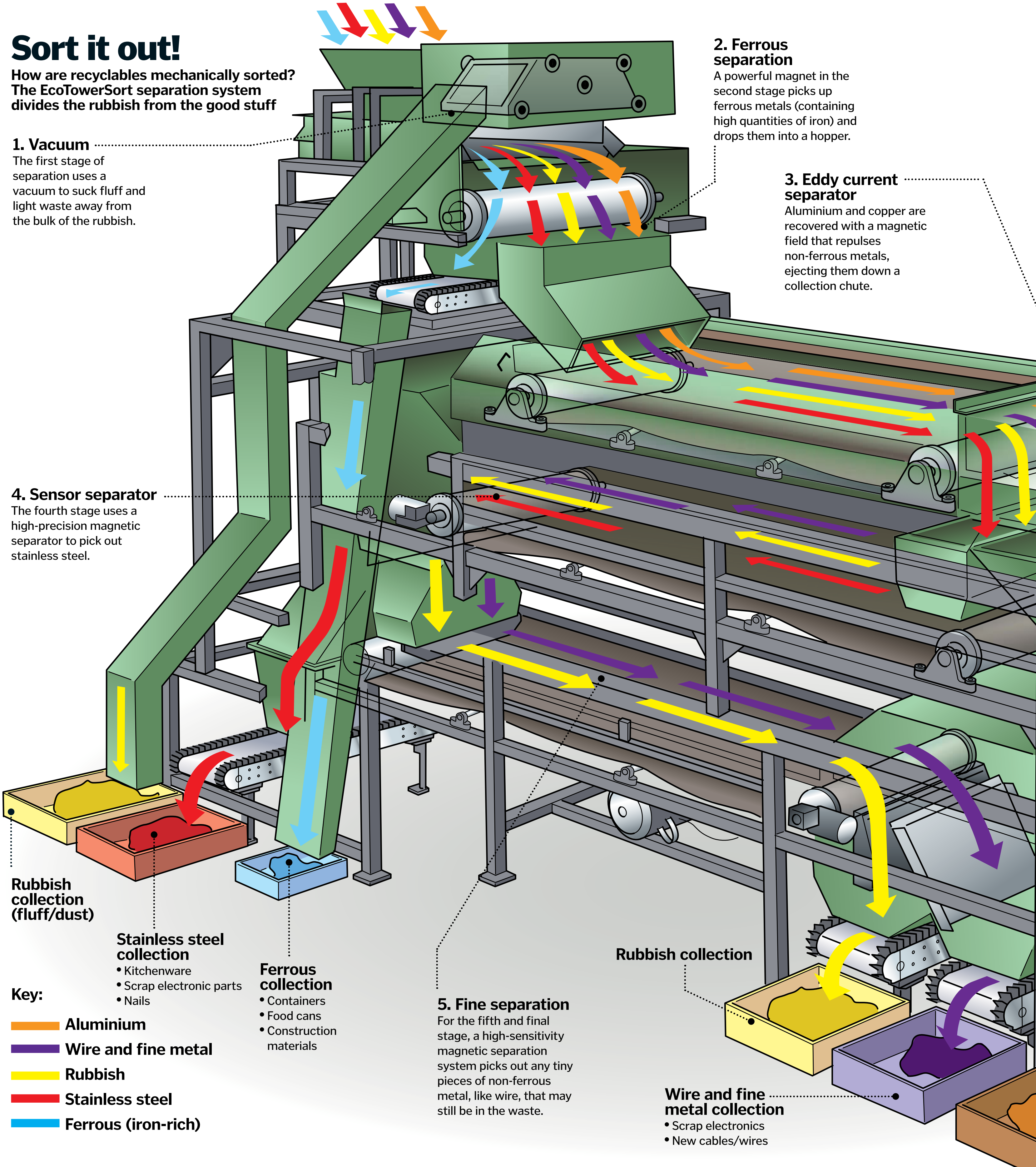
- Waste electricals: 2%
- Textiles: 3%
- Wood: 4%
- Metals: 4%
- Glass: 6%
- Plastics: 10%
- Garden & organics: 16%
- Food: 18%
- Paper & card: 23%
- Other: 14%

Source: Defra (2006-7)

> "Aluminium and copper are recovered with a magnetic field that repulses non-ferrous metals"

Sort it out!

How are recyclables mechanically sorted? The EcoTowerSort separation system divides the rubbish from the good stuff



1. Vacuum
The first stage of separation uses a vacuum to suck fluff and light waste away from the bulk of the rubbish.

2. Ferrous separation
A powerful magnet in the second stage picks up ferrous metals (containing high quantities of iron) and drops them into a hopper.

3. Eddy current separator
Aluminium and copper are recovered with a magnetic field that repulses non-ferrous metals, ejecting them down a collection chute.

4. Sensor separator
The fourth stage uses a high-precision magnetic separator to pick out stainless steel.

5. Fine separation
For the fifth and final stage, a high-sensitivity magnetic separation system picks out any tiny pieces of non-ferrous metal, like wire, that may still be in the waste.

Rubbish collection (fluff/dust)

Stainless steel collection
- Kitchenware
- Scrap electronic parts
- Nails

Ferrous collection
- Containers
- Food cans
- Construction materials

Rubbish collection

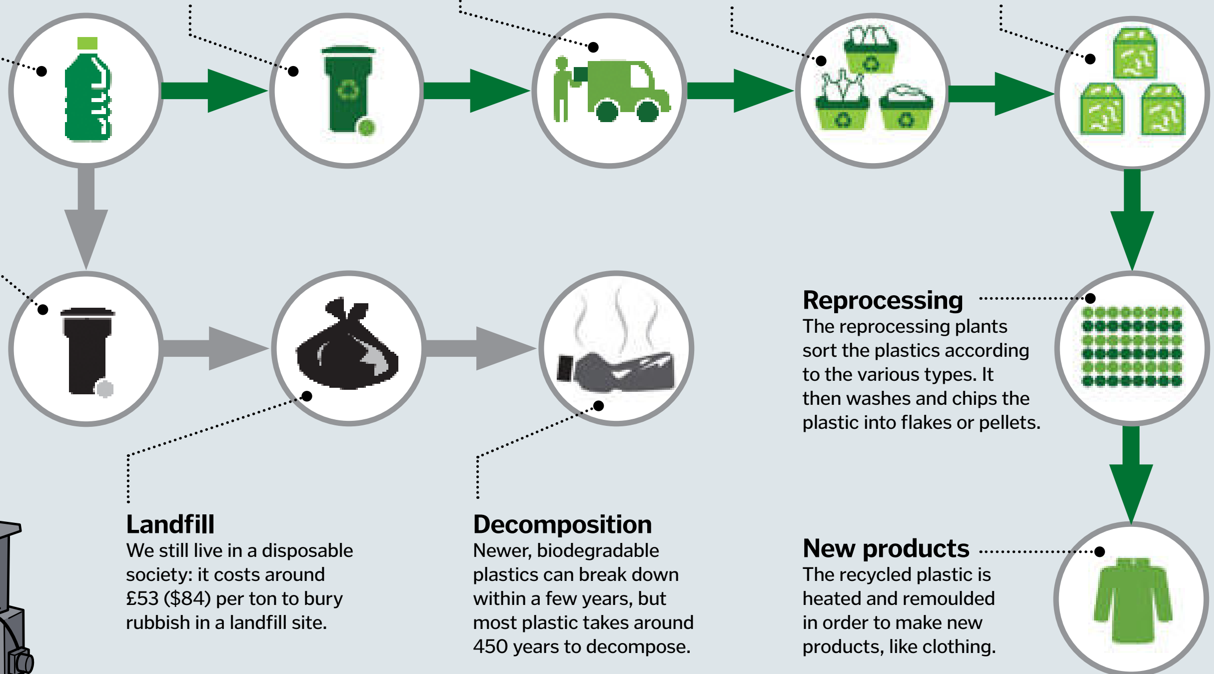
Wire and fine metal collection
- Scrap electronics
- New cables/wires

Key:
- Aluminium
- Wire and fine metal
- Rubbish
- Stainless steel
- Ferrous (iron-rich)

DID YOU KNOW? *Recycling one plastic bottle saves enough energy to power a 60W light bulb for three hours*

What happens to my drinks bottle?

Take a look at the two potential life cycles of a plastic bottle…



A bottle
Some drinks bottles are recyclable, but others aren't – often because they have already been recycled once. Recyclable plastic usually has a recognisable symbol.

Recyclable waste
We use around 20 times more plastic than we did 50 years ago. Currently about a third of the plastic bottles we chuck are recycled.

Collection
It can cost anything from £60-130 ($95-210) per ton for authorities to collect recyclable waste.

Sorting
A reclamation yard, or materials recovery facility (MRF), will sort the plastics from other recyclables for around £25 ($40) per ton.

Bale sale
Balers squash plastic bottles and turn them into cubes that can be sold to reprocessing plants for up to £280 ($450) a ton.

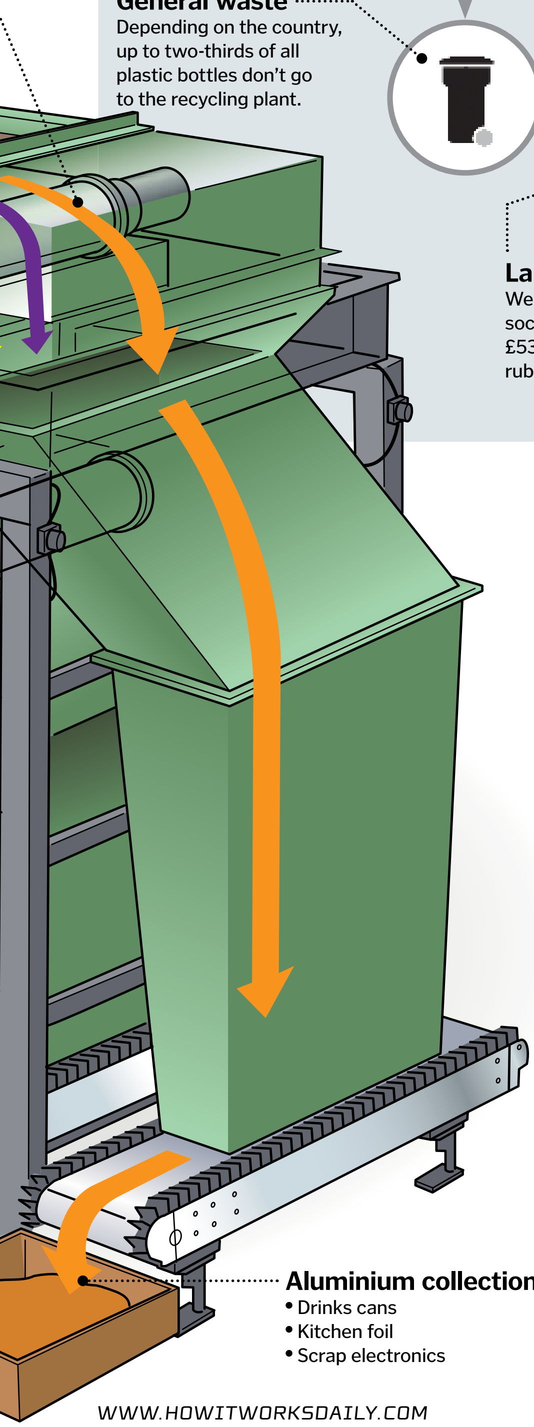
Reprocessing
The reprocessing plants sort the plastics according to the various types. It then washes and chips the plastic into flakes or pellets.

New products
The recycled plastic is heated and remoulded in order to make new products, like clothing.

General waste
Depending on the country, up to two-thirds of all plastic bottles don't go to the recycling plant.

Landfill
We still live in a disposable society: it costs around £53 ($84) per ton to bury rubbish in a landfill site.

Decomposition
Newer, biodegradable plastics can break down within a few years, but most plastic takes around 450 years to decompose.



Recycling in numbers…

40kg
Annual plastic wasted by a family

£36m
Cost of aluminium thrown away per year

9/10
of us would recycle if it were easier

250 million
trees saved if all US newspapers were recycled

24 trees to make one ton of newspapers

£150
Price of recycled PET plastic per ton

500 years
How long it takes for a nappy to decompose

© Peters & Zabransky

> "Improvements include a 1,280 x 800px HD display, a front-facing camera and a miniHDMI out port"

Inside the Kindle Fire HD

How It Works lifts the lid on Amazon's tablet to see what makes it tick

The original Kindle Fire device was launched in November 2011 as a mini-tablet version of the Kindle eReader. A year (and considerable commercial success) later and Amazon has launched the Kindle Fire HD – a tablet which now has more in common with the likes of the iPad and co than its humble eReader ancestor.

Improvements on the 17.8-centimetre (seven-inch) screen version include a 1,280 x 800 pixel HD display, a front-facing camera and a miniHDMI out port that allows for output to a bigger display. So what enhancements have been made to the hardware inside the Kindle Fire HD to power all this new technology?

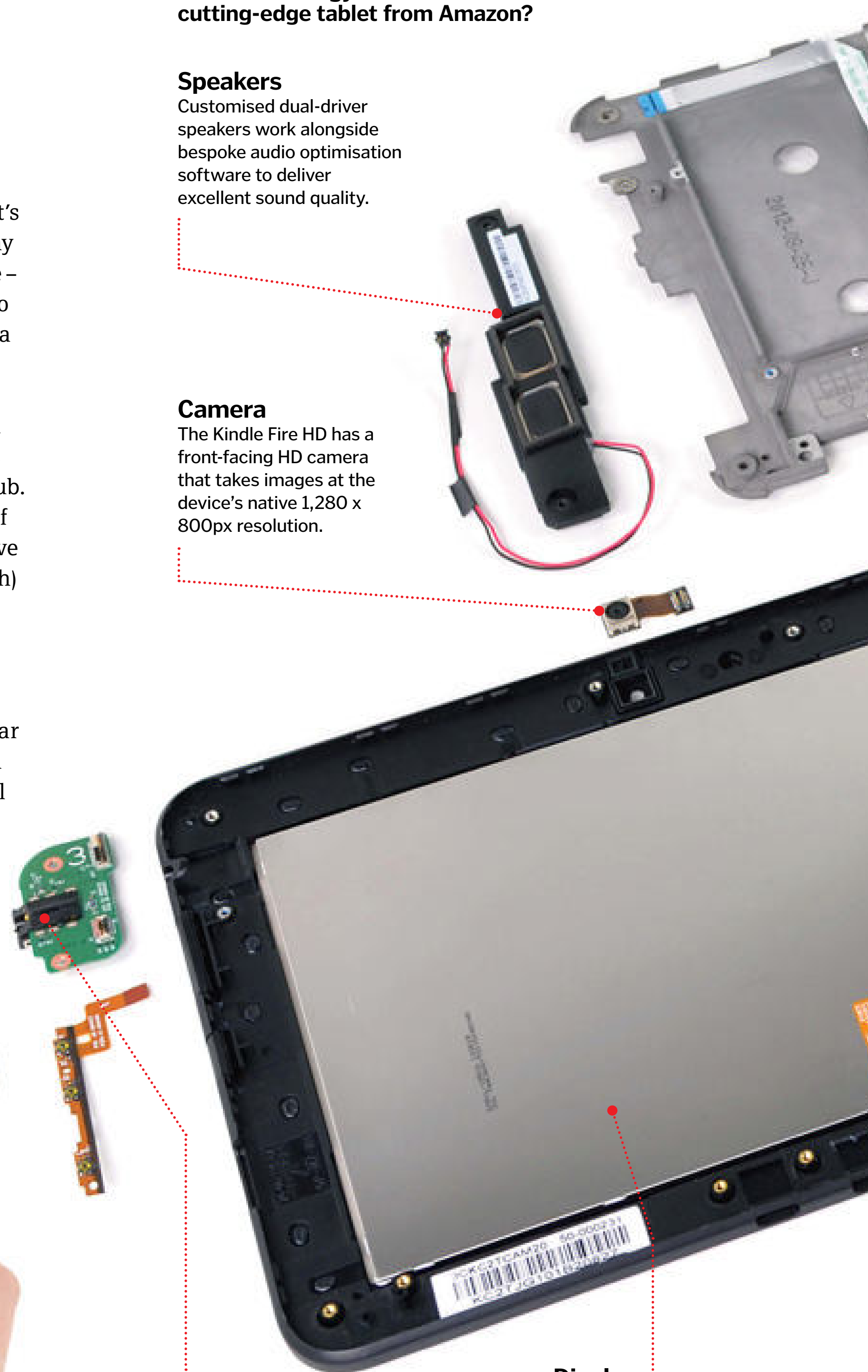
At the heart of the device are a 1.2-gigahertz, dual-core CPU, a 307-megahertz GPU and 16 gigabytes of internal memory (a 32-gigabyte option is also available) for storing hundreds of games, dozens of movies or thousands of books/music files.

This hardware is the base on which an adapted version of the Android Ice Cream Sandwich operating system is supported. It's intended as an improved gateway to Amazon's extensive catalogue – the books, videos, music and also games available for download via Amazon.com. Technically the Kindle Fire HD is an Android device, but the operating system has been so heavily modified it's like a bespoke Amazon media hub.

There are two other versions of the new Kindle Fire HD: both have a bigger 22.6-centimetre (8.8-inch) screen with a 1,920 x 1,200 pixel resolution, faster processor and graphics and a greater standard storage capacity. The high-end version also boasts 4G LTE cellular network compatibility, although commercial 4G networks are still under development in some countries, including the UK.

Tablet teardown

What technology lies inside this cutting-edge tablet from Amazon?



Speakers
Customised dual-driver speakers work alongside bespoke audio optimisation software to deliver excellent sound quality.

Camera
The Kindle Fire HD has a front-facing HD camera that takes images at the device's native 1,280 x 800px resolution.

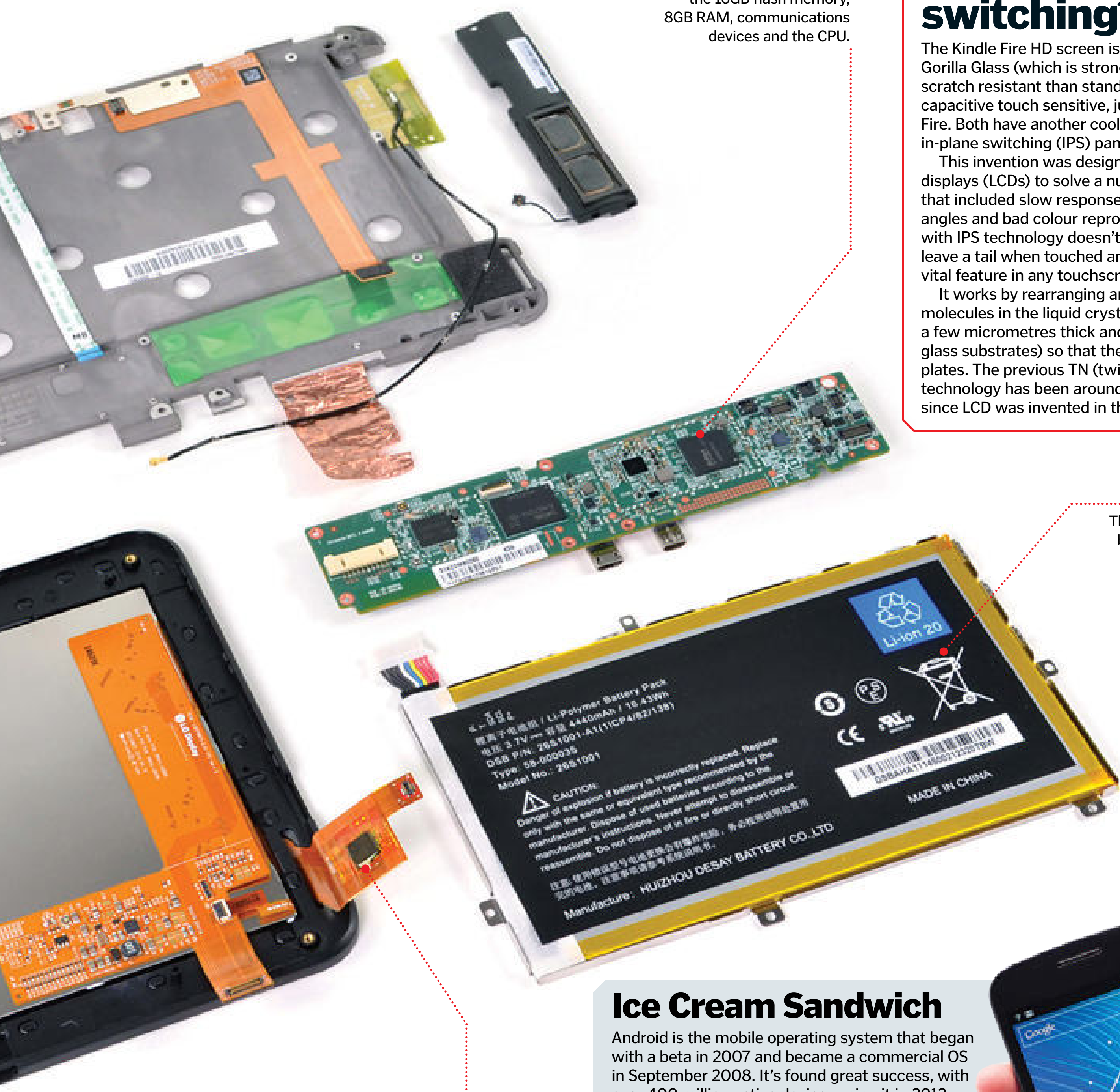
Headphone jack
Nothing remarkable about this 3.5mm (0.14in) jack, except it's standalone, so it's easily replaced if damaged.

Display
The 17.8cm (7in), 1,280 x 800 capacitive touchscreen is fused into a single piece.

THE STATS
KINDLE FIRE HD

CPU 1.2GHz | MAXIMUM STORAGE 32GB | BATTERY LIFE 11 hours
WEIGHT 395g | OS Android 4.0x | DISPLAY 178mm

DID YOU KNOW? *The Kindle Fire HD includes sponsored adverts, but by paying a little extra these can be removed*



Motherboard
The mainboard is home to the 16GB flash memory, 8GB RAM, communications devices and the CPU.

Battery
This lithium-ion 4,400mAh battery powers the Kindle Fire HD for up to 11 hours and takes up most of its internal real estate.

Capacitance controller
This is the Atmel maXTouch mutual capacitance controller – it determines which area of the screen is being touched.

© iFixit.com

What is in-plane switching?

The Kindle Fire HD screen is made of toughened Gorilla Glass (which is stronger, lighter and more scratch resistant than standard glass) and is capacitive touch sensitive, just like the Kindle Fire. Both have another cool trick though: in-plane switching (IPS) panel technology.

This invention was designed for liquid crystal displays (LCDs) to solve a number of problems that included slow response times, poor viewing angles and bad colour reproduction. A screen with IPS technology doesn't distort, brighten or leave a tail when touched and dragged – clearly a vital feature in any touchscreen device.

It works by rearranging and switching the molecules in the liquid crystal layer (which is just a few micrometres thick and lies between the glass substrates) so that they're parallel to the plates. The previous TN (twisted nematic) display technology has been around in various forms since LCD was invented in the early-Seventies.

Ice Cream Sandwich

Android is the mobile operating system that began with a beta in 2007 and became a commercial OS in September 2008. It's found great success, with over 400 million active devices using it in 2012. There have been four major revisions since version 1.0 and, since Android 1.5 Cupcake in April 2009, each new iteration has been named after a sweet or dessert. The current version of Android is 4.2 (Jelly Bean), though the Kindle Fire HD uses version 4.0.x, or Ice Cream Sandwich (ICS). Like its predecessors, the software development kit it's based on is a version of the open-source Linux OS that's been adapted for modern mobile devices. In turn, Amazon has taken ICS and created an operating system bespoke to the Kindle Fire HD, which streamlines the Amazon media experience and enables Amazon to lock out any features surplus to requirements.

“Air-abrasion drills work like a mini sandblaster that fires a stream of abrasive powder”

How dental drills work

Find out what’s inside the dentist’s high-pitched drilling device

High-speed drills are used for excavating hard enamel, while low-speed devices are better for polishing and finishing enamel

Powered by electric or air-driven motors, modern dental drills have come a long way since the early days of medieval dentistry. As well as a motor, the other main components of today’s dental drills are an ergonomic handpiece, gears and a tungsten drill bit, also known as a bur.

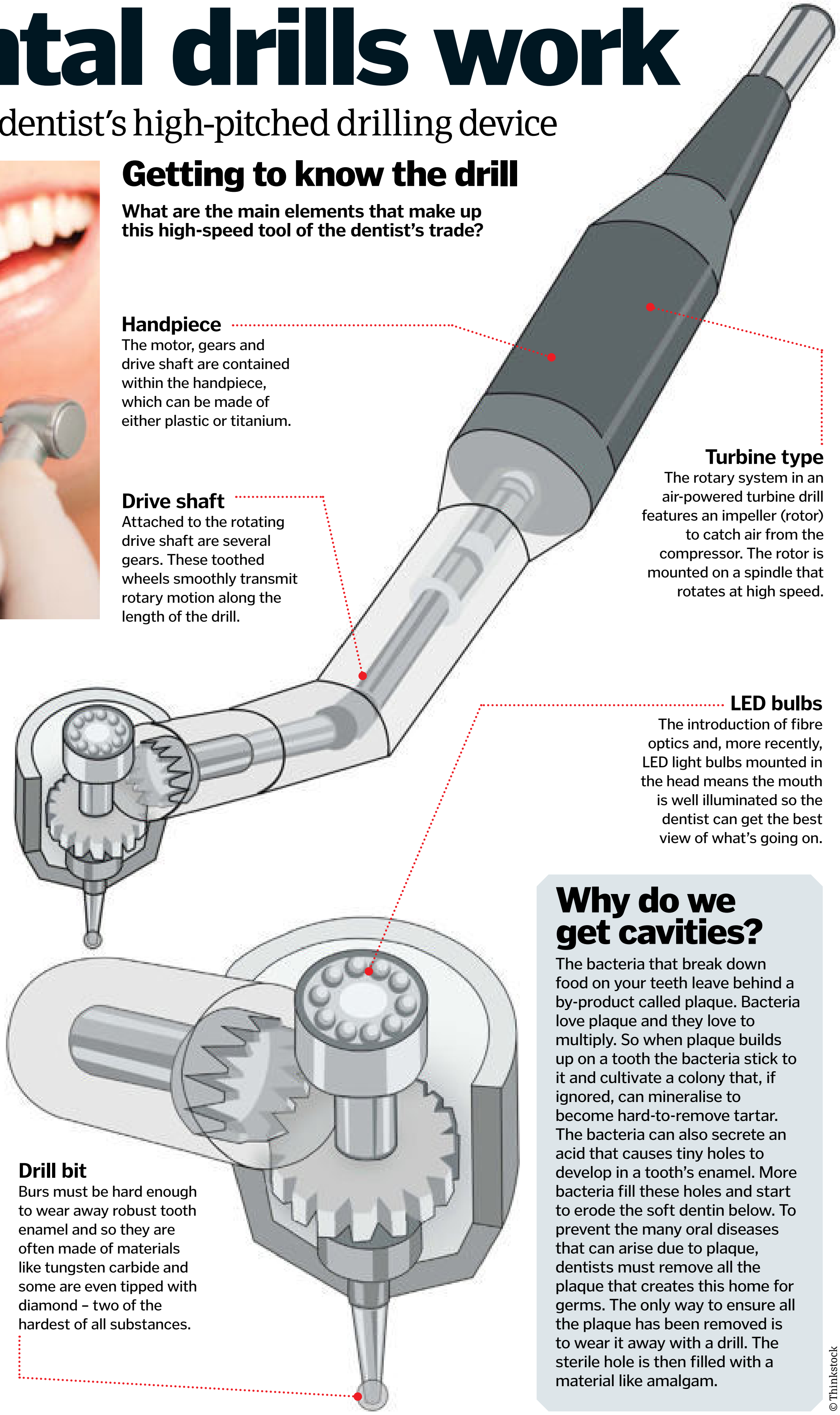
Located inside the drill’s handpiece is a series of drive shafts and gears that transmit rotary motion from the power supply to the tungsten drill bit at the head end.

Electrically motorised drills can rotate at about 30,000rpm. For a turbine-powered drill, a compressor converts pressurised air into mechanical energy that rotates the bur at over 300,000rpm. This generates a huge amount of heat, so high-speed devices are also connected to a cooling water supply.

New technologies in development – including laser and air-abrasion drills – are hoping to improve the experience of going to the dentist by providing drills that remove decay without generating the heat, noise and vibrations associated with their predecessors. The laser drill achieves this by combining the high-speed pulsed light from a laser with an atomised spray of water droplets to generate hydrokinetic energy. Air-abrasion drills, meanwhile, work like a mini sandblaster that fires a stream of abrasive powder (such as silica or ammonium oxide) at the tooth to blast the decay away.

Getting to know the drill

What are the main elements that make up this high-speed tool of the dentist’s trade?



Why do we get cavities?

The bacteria that break down food on your teeth leave behind a by-product called plaque. Bacteria love plaque and they love to multiply. So when plaque builds up on a tooth the bacteria stick to it and cultivate a colony that, if ignored, can mineralise to become hard-to-remove tartar. The bacteria can also secrete an acid that causes tiny holes to develop in a tooth’s enamel. More bacteria fill these holes and start to erode the soft dentin below. To prevent the many oral diseases that can arise due to plaque, dentists must remove all the plaque that creates this home for germs. The only way to ensure all the plaque has been removed is to wear it away with a drill. The sterile hole is then filled with a material like amalgam.

RECORD BREAKERS
SUPER-SAFE

100,000kg

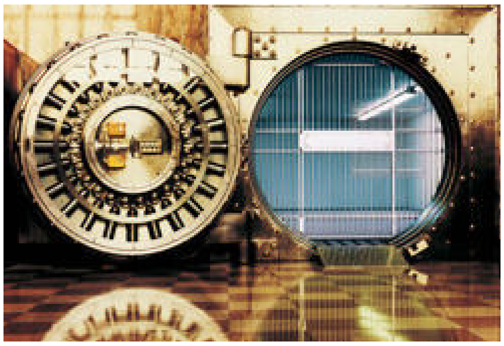
HEAVIEST VAULT DOOR

Found in the Federal Reserve Bank of Cleveland, this 100-ton vault door is the stuff of bank robbers' nightmares! It hangs on a 47-ton hinge.

DID YOU KNOW? *Trinity Place Bar & Restaurant in New York is situated inside a decommissioned bank vault*

How are bank vaults built?

Learn how these walk-in safes are made step by step



The first step in creating a bank vault is to build its wall panels. These are made from concrete with zero 'slump', a quality that means it is super-strong and sets very quickly when put into the moulds. While the concrete is still damp, steel rods are inserted to provide extra strength. The entire moulds are then vibrated for several hours – this oscillation settles the concrete around the rods and eliminates any air pockets.

Once the panels are fitted, the vault door can be made. This involves creating a core panel of concrete and then cladding it in reinforced stainless steel. The door is slotted into the wall panels by metal struts. When the door is done the locking mechanism can be installed, which is placed on the inward side of the door for obvious security reasons.

Typically a dual-combination lock is used, which requires two people to synchronously dial in for the door to open. Finally, a suite of alarm sensors is installed both inside and around the vault. These include CCTV video cameras, laser trip-wires, motion sensors and decibel sensors.

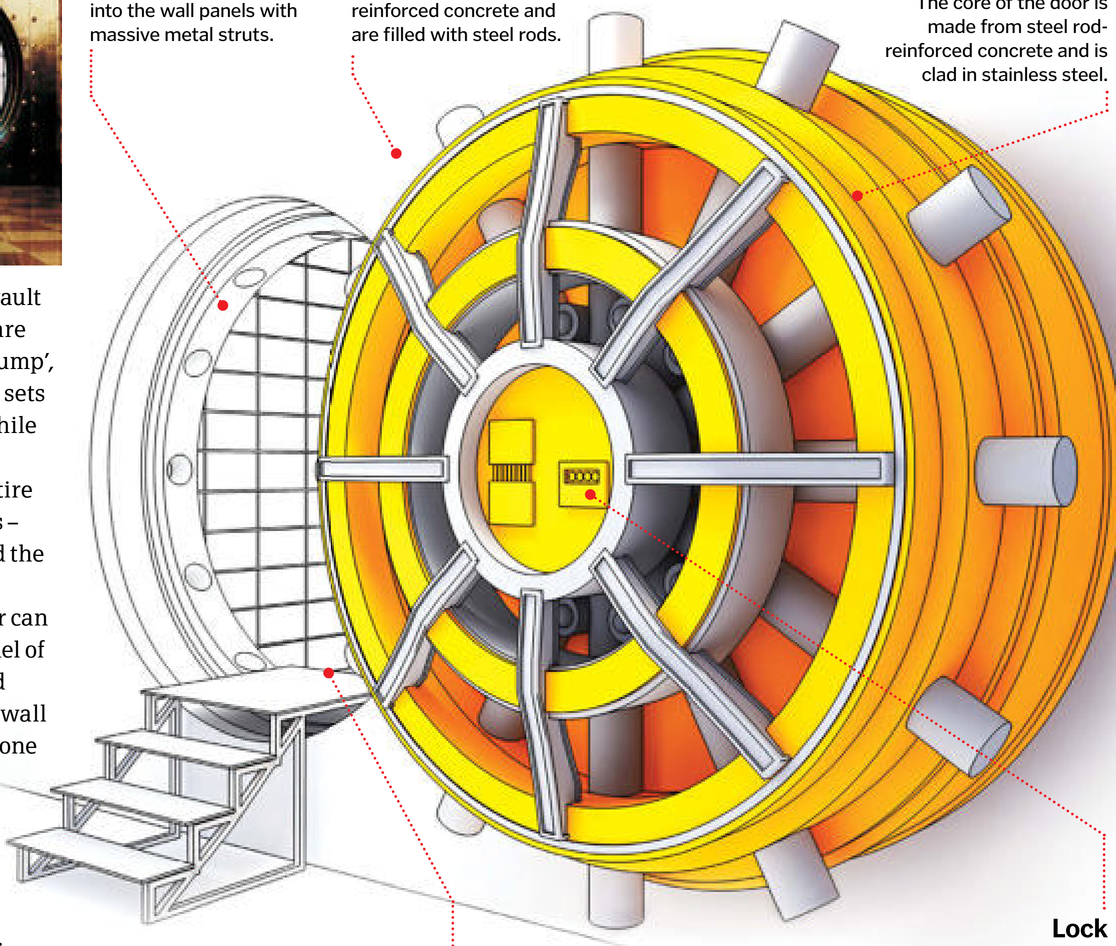
Anatomy of a strongroom

What are the core components of these giant safes?

Frame
A one-piece steel frame is custom built and slotted into the wall panels with massive metal struts.

Walls
Wall panels are made from reinforced concrete and are filled with steel rods.

Door
The core of the door is made from steel rod-reinforced concrete and is clad in stainless steel.



Alarms
Visual, audible, movement and laser sensors are positioned both inside and in the vicinity of the vault.

Lock
Today, dual-combination locks are popular, which are also connected to a time lock. These require two people to open and will only work at set times.

© Thinkstock

"Both mobile and landline local exchanges filter long-distance calls through a central exchange"

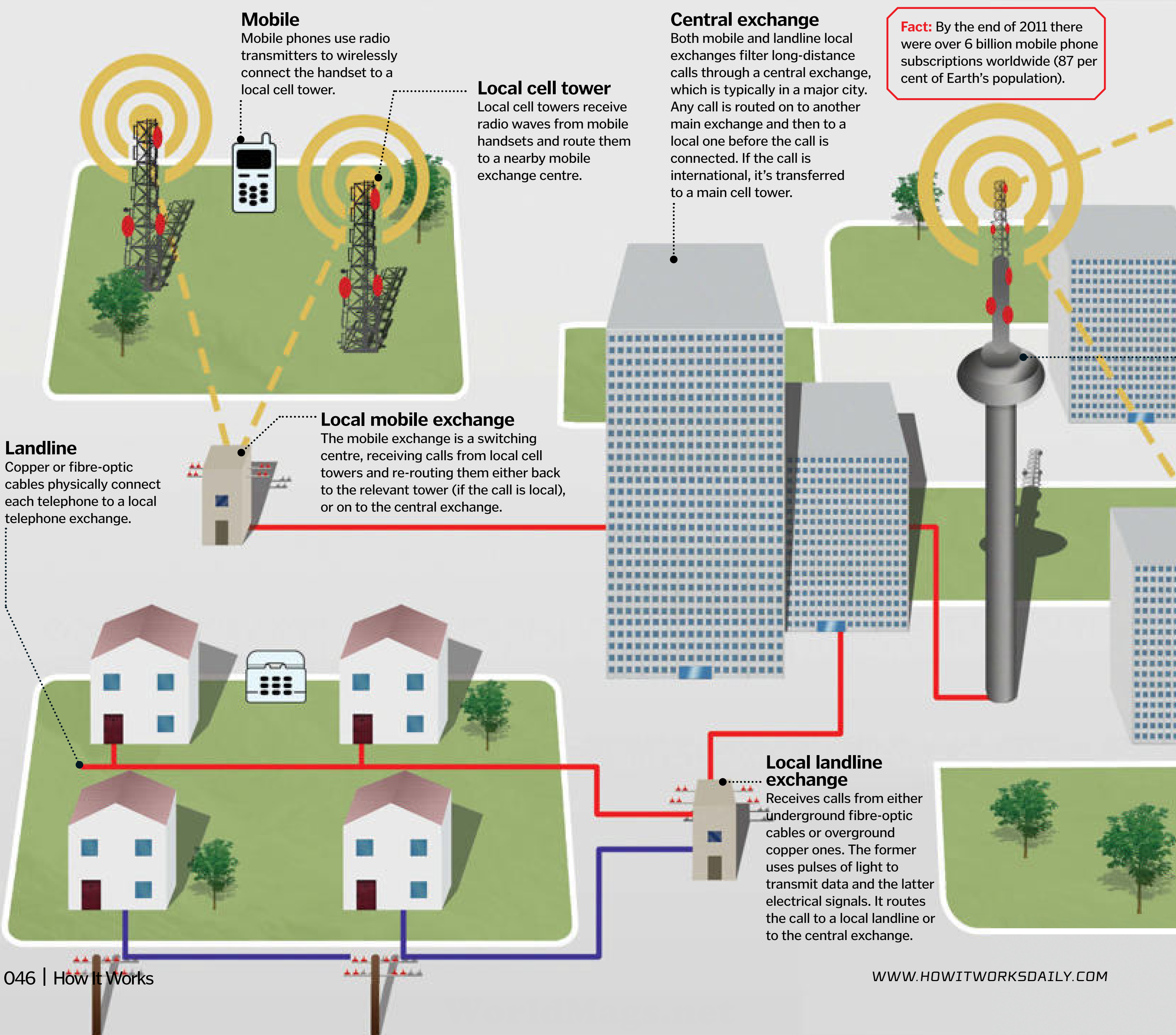
How phone calls are connected

A closer look at the extensive web of technology that powers the field of telecommunication

Regardless of whether a person is making a call on a landline or mobile phone, or whether they are calling the local garage or a relative living on the other side of the world, a complex series of networks and routing technology is required to connect them. Follow this step-by-step guide to discover how the whole process works…

Key

- Underground fibre-optic cable
- Overhead electrical cable
- Microwaves
- Submarine cable



Mobile

Mobile phones use radio transmitters to wirelessly connect the handset to a local cell tower.

Local cell tower

Local cell towers receive radio waves from mobile handsets and route them to a nearby mobile exchange centre.

Central exchange

Both mobile and landline local exchanges filter long-distance calls through a central exchange, which is typically in a major city. Any call is routed on to another main exchange and then to a local one before the call is connected. If the call is international, it's transferred to a main cell tower.

Fact: By the end of 2011 there were over 6 billion mobile phone subscriptions worldwide (87 per cent of Earth's population).

Landline

Copper or fibre-optic cables physically connect each telephone to a local telephone exchange.

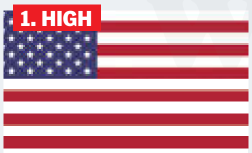
Local mobile exchange

The mobile exchange is a switching centre, receiving calls from local cell towers and re-routing them either back to the relevant tower (if the call is local), or on to the central exchange.

Local landline exchange

Receives calls from either underground fibre-optic cables or overground copper ones. The former uses pulses of light to transmit data and the latter electrical signals. It routes the call to a local landline or to the central exchange.

HEAD 2 HEAD
MOBILE PHONES PER COUNTRY

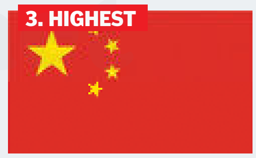


1. HIGH

USA
With almost 330 million mobile phones in use within a population of just over 311 million, there are a lot more active mobiles in America than people.

2. HIGHER

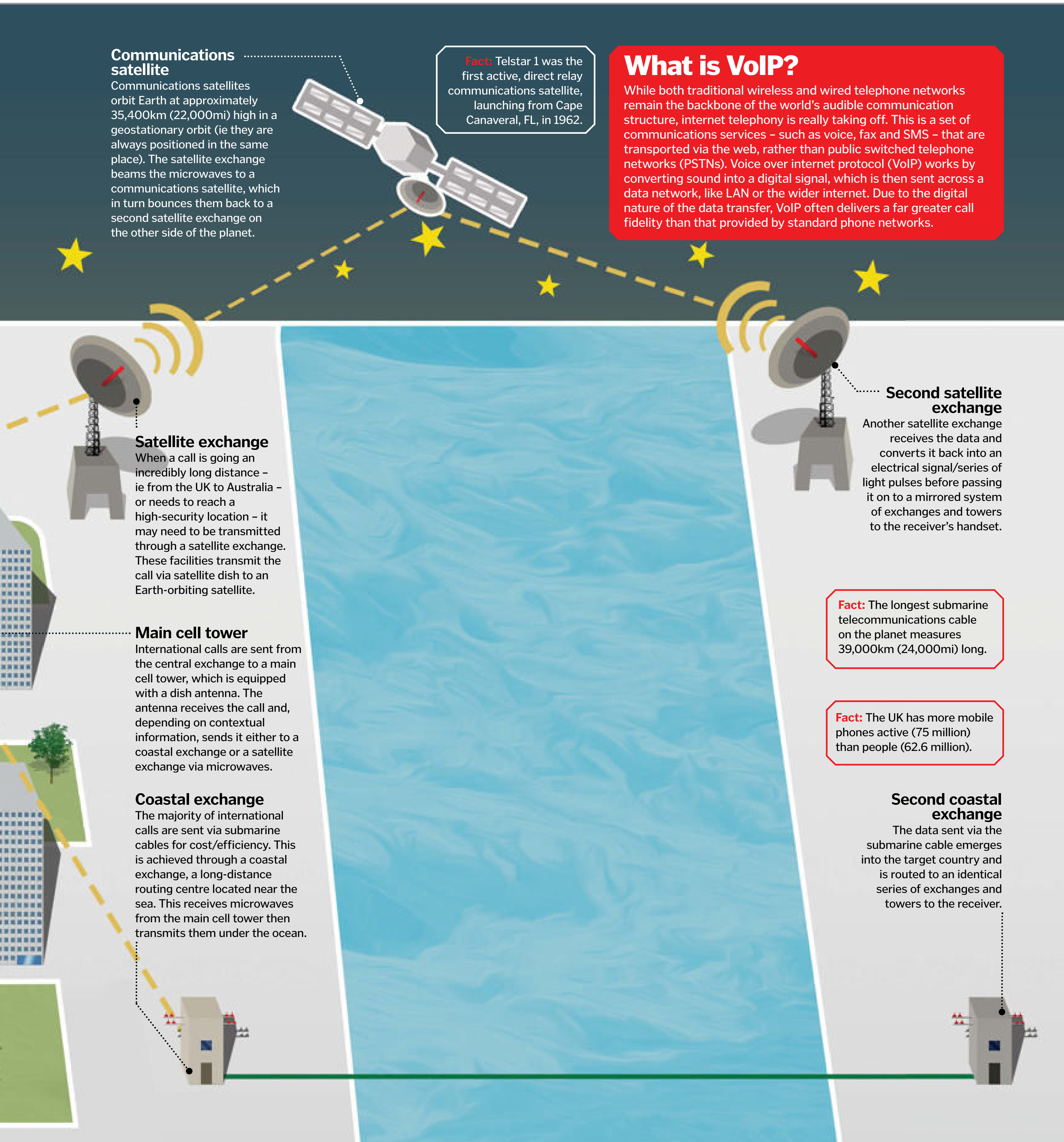
India
A rapidly growing economy and population has led to more than 908 million mobiles being taken up in India – about 73 per cent of the population!



3. HIGHEST

China
There are over 1.05 billion mobile phones active in China as of June 2012. With a population of 1.34 billion, that's 75 per cent of the total populace.

DID YOU KNOW? A satellite call from Europe to the USA has to travel over 72,000km (44,000mi)



Communications satellite
Communications satellites orbit Earth at approximately 35,400km (22,000mi) high in a geostationary orbit (ie they are always positioned in the same place). The satellite exchange beams the microwaves to a communications satellite, which in turn bounces them back to a second satellite exchange on the other side of the planet.

Fact: Telstar 1 was the first active, direct relay communications satellite, launching from Cape Canaveral, FL, in 1962.

What is VoIP?
While both traditional wireless and wired telephone networks remain the backbone of the world's audible communication structure, internet telephony is really taking off. This is a set of communications services – such as voice, fax and SMS – that are transported via the web, rather than public switched telephone networks (PSTNs). Voice over internet protocol (VoIP) works by converting sound into a digital signal, which is then sent across a data network, like LAN or the wider internet. Due to the digital nature of the data transfer, VoIP often delivers a far greater call fidelity than that provided by standard phone networks.

Satellite exchange
When a call is going an incredibly long distance – ie from the UK to Australia – or needs to reach a high-security location – it may need to be transmitted through a satellite exchange. These facilities transmit the call via satellite dish to an Earth-orbiting satellite.

Main cell tower
International calls are sent from the central exchange to a main cell tower, which is equipped with a dish antenna. The antenna receives the call and, depending on contextual information, sends it either to a coastal exchange or a satellite exchange via microwaves.

Coastal exchange
The majority of international calls are sent via submarine cables for cost/efficiency. This is achieved through a coastal exchange, a long-distance routing centre located near the sea. This receives microwaves from the main cell tower then transmits them under the ocean.

Second satellite exchange
Another satellite exchange receives the data and converts it back into an electrical signal/series of light pulses before passing it on to a mirrored system of exchanges and towers to the receiver's handset.

Fact: The longest submarine telecommunications cable on the planet measures 39,000km (24,000mi) long.

Fact: The UK has more mobile phones active (75 million) than people (62.6 million).

Second coastal exchange
The data sent via the submarine cable emerges into the target country and is routed to an identical series of exchanges and towers to the receiver.

“They’re designed to provide safety from anything nature or man can throw at them”

Next-gen nuclear bunkers

Disaster shelters are still big business, but what’s inside a modern nuclear bunker?

There are a number of reasons why a disaster shelter might be built. Along the east coast of the United States and parts of the Asian coastline, they protect people from hurricanes, flooding and typhoons. In earthquake-prone regions, they shelter people from falling buildings and provide an escape route from surface rubble when all is clear. And typically across the Great Plains of the US, simple but sturdy shelters offer a safe subterranean retreat from tornadoes wreaking havoc on the surface.

Nuclear bunkers are the most robust of these shelters. They’re designed to provide comprehensive safety from anything nature or man can throw at them, plus life support for many months – and even years for the most sophisticated examples. Smaller varieties tend to come pre-assembled, but larger and bespoke shelters are usually installed on site. The modern shape is a corrugated curve, made of fibreglass and composite, fire retardant and even bulletproof (for the entrance) materials. They’re designed to avoid tensile loads, while seismic joints can withstand the kind of forces an 8.5-magnitude earthquake might yield.

Modern nuclear bunkers are sealed to prevent contamination from nuclear fallout and also to keep deadly radon gas and airborne toxins out, including weaponised viruses and bacteria. In addition, an ‘overpressure choking’ system with no moving parts prevents a nearby blast from causing excessive pressure inside the shelter.

New nuclear bunkers are still a profitable business today despite the decades that have passed since the Cold War ended. While they are a fascinating feature for any household to have, we can only hope that no one ever has to use them for their intended purpose.

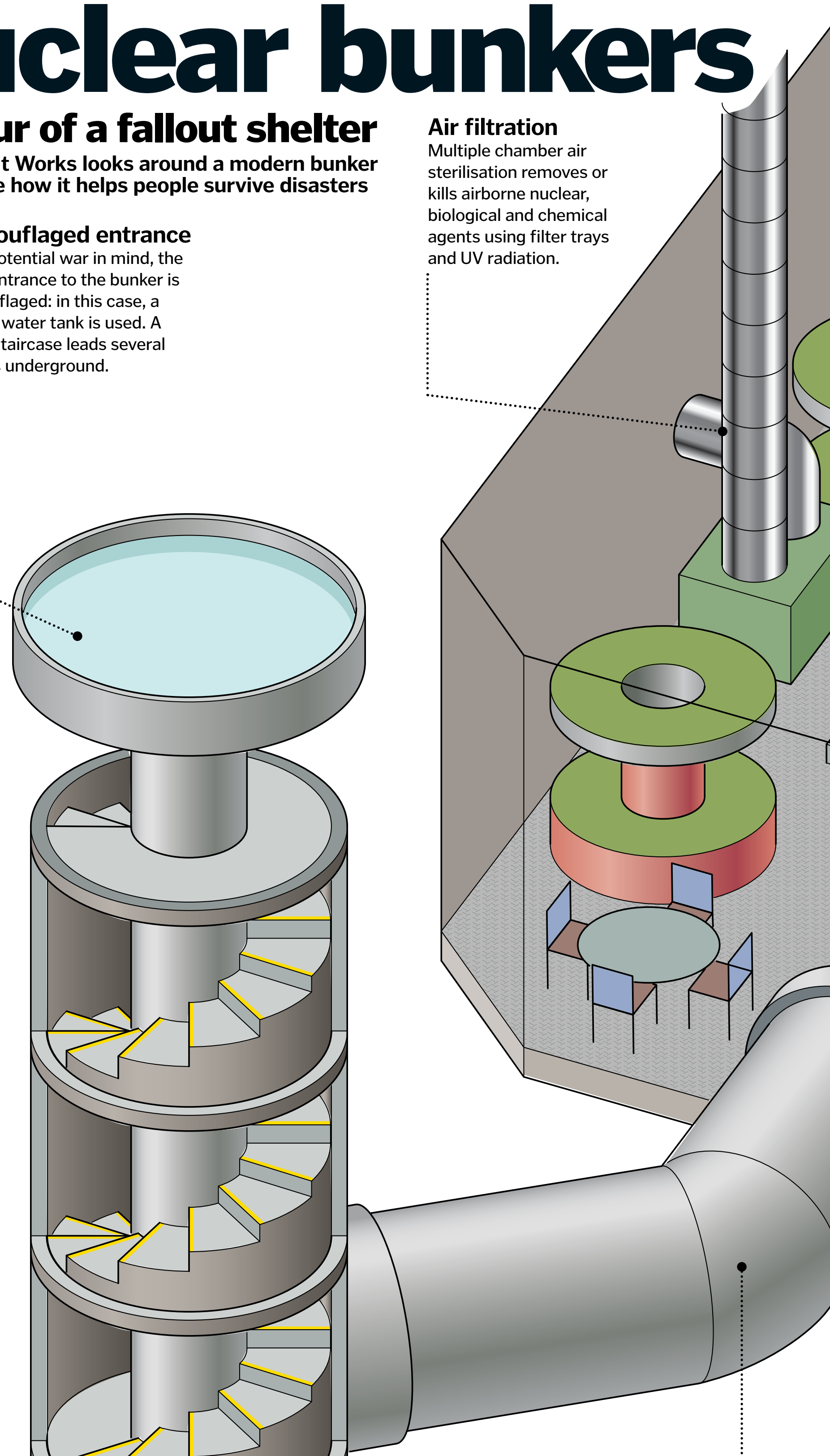
A sheltered life

Surviving the initial blast, the terrible heat and deadly radiation from a nuclear explosion is one thing, but the radioactive fallout alone can be enough to stop you from venturing outside for weeks. Basic accommodation in a good nuclear bunker will include a plumbing system with a ceramic water filter and high-pressure pump to keep drinking water clean and pass ‘grey water’ on for storage and potential recycling.

A longer-term bunker might include a hydroponics bay in which the grey water can be used to irrigate plants. Bunk beds come as standard and a well-stocked shelter will include dried, preserved goods, tinned food and other non-perishables that will last for an extended stay. Crucially important is some form of power generator as well as a battery backup, plus shielding for essential electronics like radios in the event of an electromagnetic pulse that can destroy sensitive equipment.

Tour of a fallout shelter

How It Works looks around a modern bunker to see how it helps people survive disasters



Camouflaged entrance
With potential war in mind, the main entrance to the bunker is camouflaged: in this case, a simple water tank is used. A spiral staircase leads several metres underground.

Air filtration
Multiple chamber air sterilisation removes or kills airborne nuclear, biological and chemical agents using filter trays and UV radiation.

Radiation bend
In places where radiation can more easily enter, such as open walkways, a simple bend in the passage can reduce transmission.

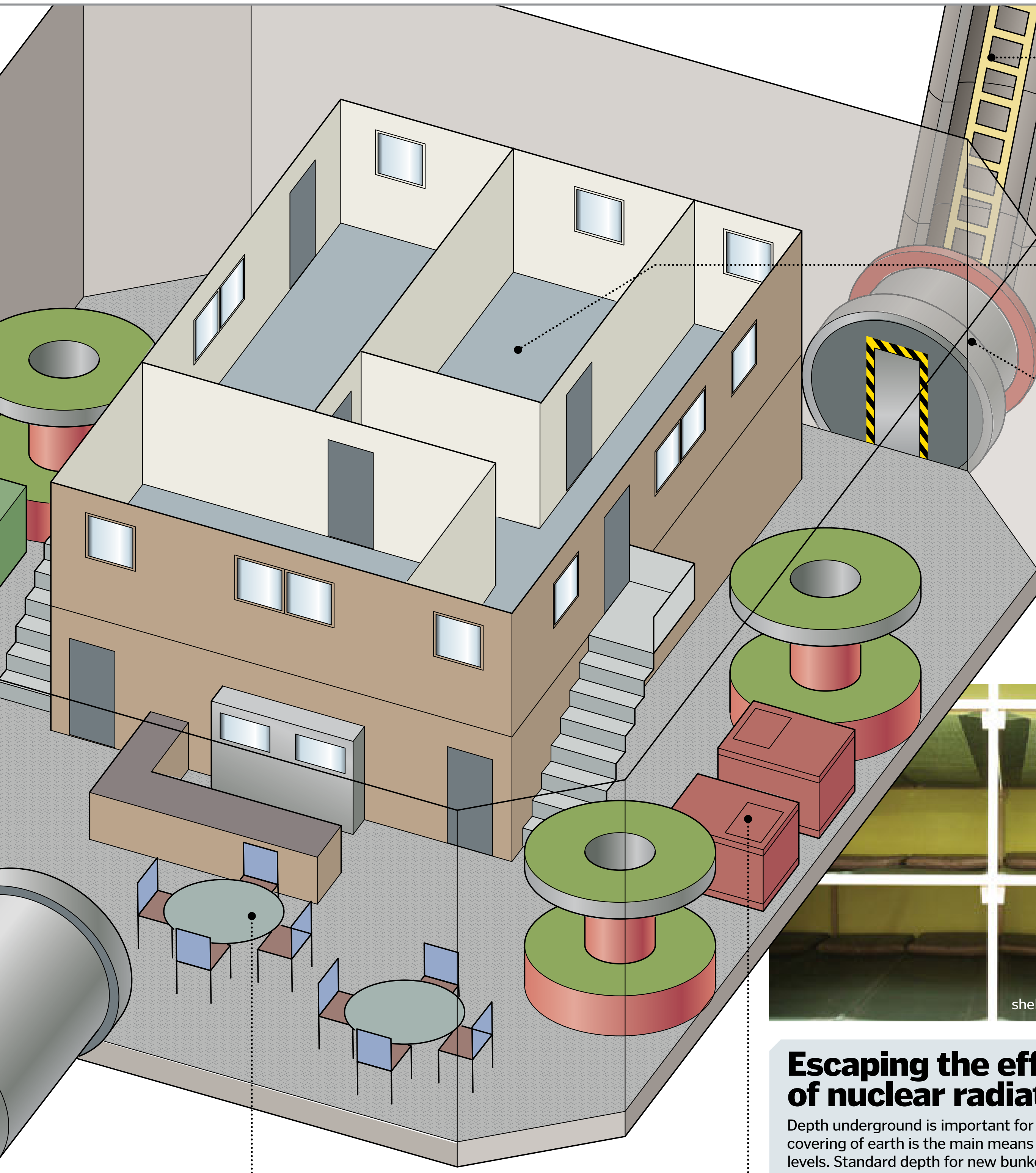
STRANGE BUT TRUE
BUNKERS DEBUNKED

What else can a nuclear bunker be used for?

A A hotel **B** A library **C** A bank

Answer:
The Null Stern Hotel is a converted Swiss Cold War bunker in Sevelen, near Zurich. This Spartan accommodation – now a museum – was given a zero-star rating and cost £5.80 ($9.50) a night, though it was open 24 hours in case of emergency.

DID YOU KNOW? *In the Cold War, the US legislated fallout shelters that could withstand a 50-megaton blast for all new homes*



Escape hatch
In case the main entrance is blocked, an emergency hatch like this provides an alternative way out.

Sleeping area
Living space is at a premium, so bunk beds would probably be used for their small footprint.

Seismic joint
Both watertight and soundproofed, this seismic joint is a buffer protecting an exit tunnel from separation during a seismic event.

Generator
Power is of course critical to survival, so low-noise diesel generators are backed up by pre-charged battery systems.

Dining area
This is a communal area where people would eat. The bunker would probably have its own hydroponics bay to grow fresh produce.

Bunk beds at Lucerne's Sonnenberg nuclear fallout shelter, which could sleep 20,000

Escaping the effects of nuclear radiation

Depth underground is important for nuclear shelters as the covering of earth is the main means of mitigating radiation levels. Standard depth for new bunkers is just over 2.5 metres (8.5 feet), designed to reduce an overhead burst of deadly radiation from a one-megaton bomb to less than the effect of a single chest X-ray (0.01 sieverts) – which is harmless.

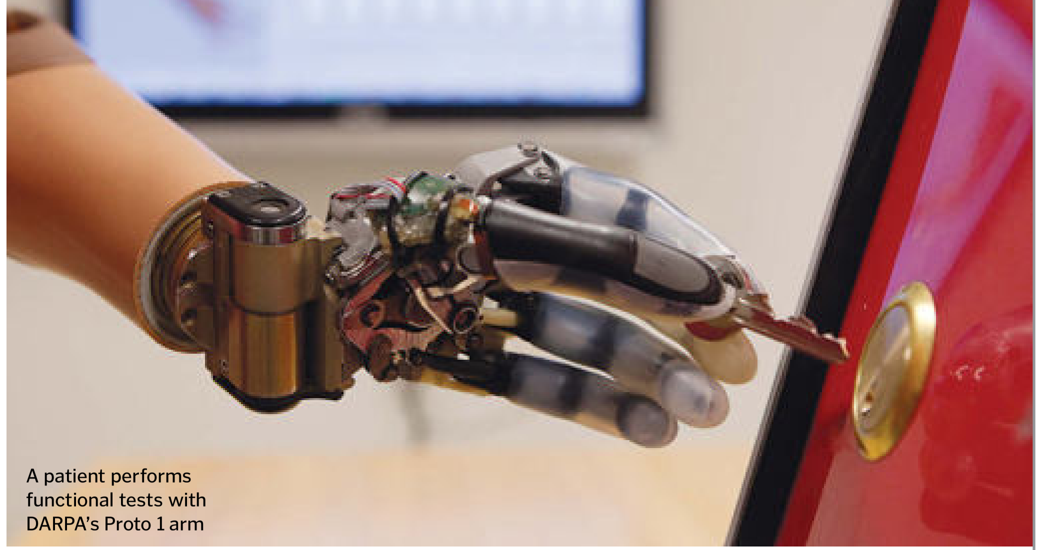
The sievert is used to measure the biological effects of radiation. From the gamma and neutron sources that characterise the deadliest parts of a nuclear blast's radiation burst, a person in good health can be exposed to a dose of up to 0.25 sieverts and suffer no ill-effects.

Curiously, a smaller 500-kiloton nuclear bomb exploding in the air can be more lethal than a much larger weapon on the ground. This is because nuclear air bursts produce much more deadly neutron radiation than surface bursts.

"The initial crude devices are now being replaced with technologically cutting-edge equipment"

How brains can control prostheses

Learn how scientists are using the mind to manipulate life-changing technology



A patient performs functional tests with DARPA's Proto 1 arm

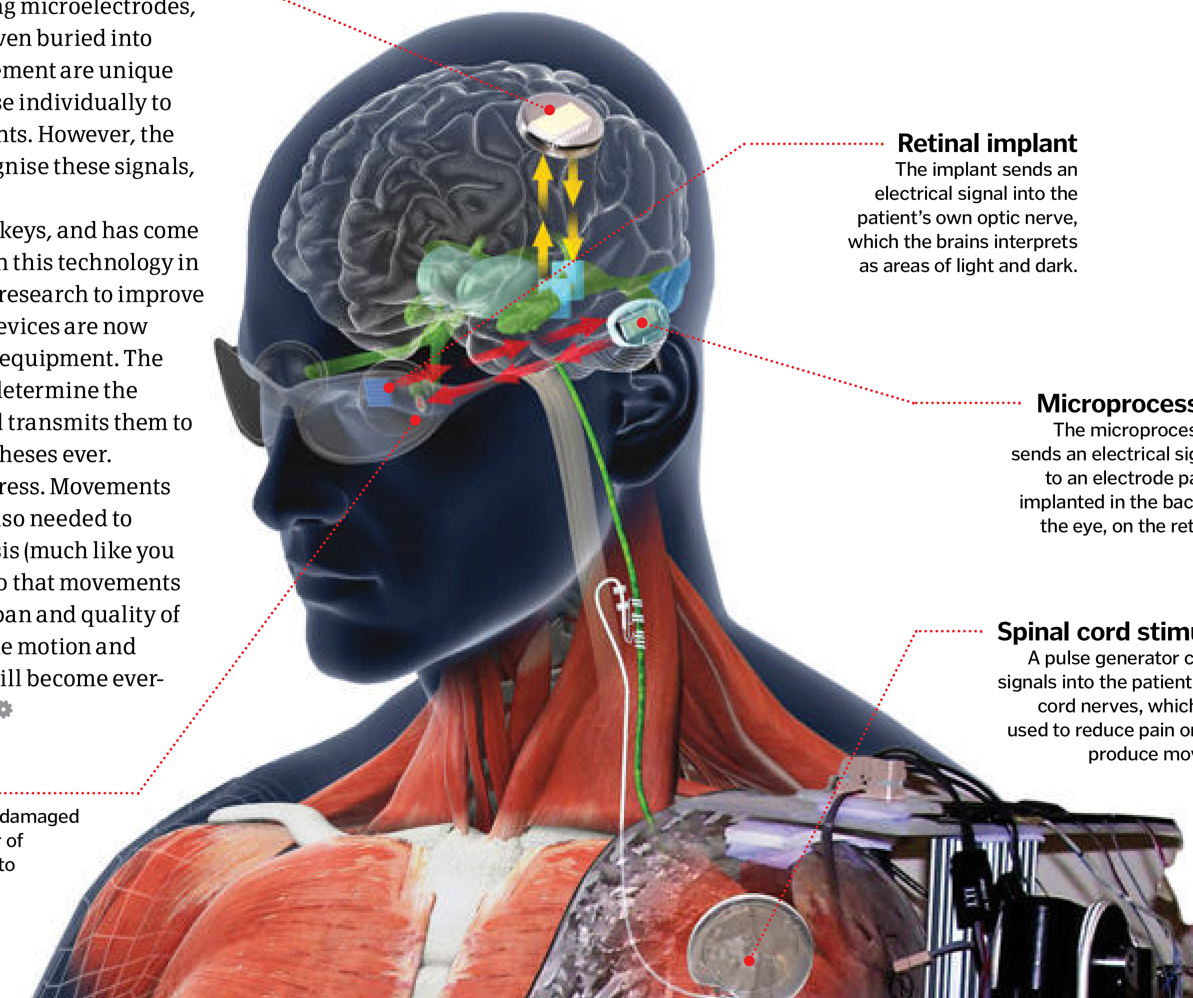
Scientists are exploiting ways to connect the human brain to modern prostheses (such as artificial limbs) or via computers to expand our functionality. It's hoped patients will be the ones to benefit, particularly those who have lost limbs in accidents or at war. Motor prostheses interpret the natural signals sent from the brain. The electrical signals sent are detected using microelectrodes, which can be implanted underneath the skin or even buried into nerves. The brain signals for each particular movement are unique and slightly different, and the aim is to detect these individually to allow patients the ability to perform fine movements. However, the science is still developing to more accurately recognise these signals, and the perfect prosthesis does not yet exist.

The initial technology was developed with monkeys, and has come a long way since. There has been a massive push in this technology in recent years, as military funding starts to finance research to improve injured soldiers' quality of life. The initial crude devices are now being replaced with technologically cutting-edge equipment. The most modern devices use hundreds of sensors to determine the precise movements the brain is commanding, and transmits them to some of the most complex and sophisticated prostheses ever.

That said, this technology is still a work-in-progress. Movements are still limited and require refinement. Work is also needed to improve feedback to the patient from the prosthesis (much like you can feel what you're touching with your fingers), so that movements can become even more realistic. As both the life span and quality of the microprocessors improve, the motion and functionality of prostheses will become ever-more reliable and lifelike.

Where modern prostheses can make a difference

The latest prostheses are a combination of biology, technology and state-of-the-art design



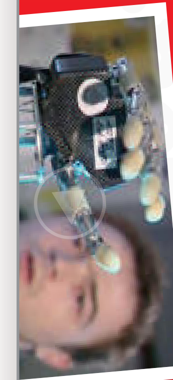
Brain signals
Microprocessors to control movement of the limbs can be implanted near the brain to detect early signals.

Retinal implant
The implant sends an electrical signal into the patient's own optic nerve, which the brains interprets as areas of light and dark.

Microprocessor
The microprocessor sends an electrical signal to an electrode panel implanted in the back of the eye, on the retina.

Spinal cord stimulator
A pulse generator can send signals into the patient's spinal cord nerves, which can be used to reduce pain or to help produce movement.

Bionic eye
For patients who have a damaged retina, a camera in a pair of glasses sends an image to the microprocessor.



DID YOU KNOW? *Upper limb tech is far harder to perfect than lower limb tech, as it demands much finer movements*

Myoelectric prostheses

This cutting-edge prosthesis combines the best possible function with a pleasing aesthetic finish. Rather than using cables and pulleys like older prostheses, this uses batteries and microprocessors to interpret the brain's electrical activity. The main disadvantages are its current weight and expense, although both are coming down rapidly.

This myoelectric-driven grip prosthesis, known as the Michelangelo Hand, is made by Ottobock

History of prostheses

A look at some of the most game-changing developments in the world of prosthetics

1957
First cochlear implant
The first cochlear implant converts sound waves into strong electrical impulses and still brings improved hearing to many people around the globe.

1990s
CAT-CAM
The widespread introduction of the modern fitting limb prosthesis – the contoured adducted trochanteric-controlled alignment method (CAT-CAM) – paves the way for the development of today's sophisticated prostheses.

2002
Median nerve cybernetics
A microelectrode array is implanted into a healthy volunteer's median nerve located in the arm, which enables him to control hand functions.

2008
Monkeys
Two monkeys learn to feed themselves marshmallows using a robotic arm controlled by a computer that's linked to their brains.

2009
Modular prosthetic limb
Developed by the USA's Defense Advanced Research Projects Agency (DARPA), this prosthesis offers 22 degrees of motion with independent movement of each finger. The Proto prosthesis is still being developed to this day.

Horse power

Explore the anatomy of these natural-born runners and see how life works in the herd

Horses and cows might stand in the same fields but they are quite different animals. In fact, horses are more closely related to the rhinoceros and the tapir than they are other farm animals. The ancestors of the horse were small deer or pig-like creatures that lived in forests. As grasslands began to spread around the world 50 million years ago, the early horses moved to the plains and developed tougher teeth to cope with grazing. Exposed on the open plain, they banded together into herds for safety and, over the next 40 million years, gradually evolved longer and longer legs to outrun their predators.

A lion or a wolf can flex its spine as it runs, as a way of increasing its effective stride length. Horses can't do this because they have to suspend a large barrel-shaped body, full of slowly digesting grass. That requires a stiff, inflexible spine for support. So instead they evolved to run on their ▶

The statistics...

Horse

Type: Mammal

Genus: Equus

Diet: Herbivore, eg grass

Average life span in the wild: 25-30 years

Weight: Up to 1,000kg (2,200lb)

Height: Up to 183cm (72in) at the withers (shoulders)

5 TOP FACTS HORSE BREEDS

Belgian draught
1 The world's largest horse was a Belgian draught named Brooklyn Supreme, who weighed 1,500 kilograms (3,307 pounds) and stood 198 centimetres (78 inches) tall.

Camargue
2 Native to the wetlands of southern France, the Camargue may be one of the oldest breeds in the world. Semi-feral populations date back thousands of years.

Icelandic
3 By law it's decreed this is the only breed of horse that's allowed on Iceland. They have two unique gaits: a four-beat, ambling gait and a two-beat, side-to-side 'flying gait'.

Lipizzaner
4 Bred by the Habsburg nobility in the 16th century and made famous by the Spanish Riding School of Vienna for their high jumping and stylised dressage manoeuvres.

Thoroughbred
5 All modern Thoroughbreds are descended from one of three stallions imported to Britain in the 17th and 18th centuries. They are good at both racing and showjumping.

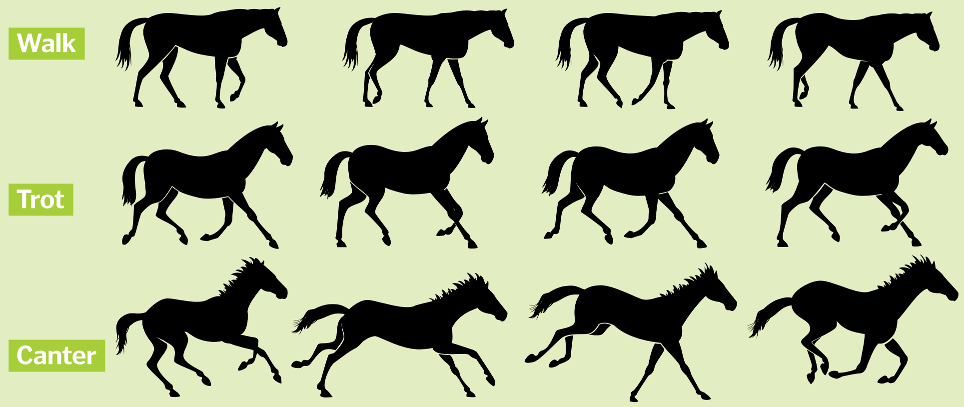
DID YOU KNOW? Horses can sleep standing up, but must lie down for 1-2 hours a day for REM sleep to be fully rested

How do horses get around?

Horses have four natural gaits – patterns of placing their feet as they move. The slowest is the walk, where the legs move one at a time from left-hind to left-front, then right-hind to right-front. Only one foot is ever off the ground at a time. A walking horse moves most comfortably at about 6.4 kilometres (four miles) per hour.

As it begins to move faster there isn't time for the right-hand legs to wait for the left-hand ones to finish moving. Instead the legs move in diagonally opposite pairs: left-hind and right-front, alternating with right-hind and left-front. This is the trot and it is the most efficient gait for a horse. Horses can trot at 12.9 kilometres (eight miles) per hour for hours. To move faster, the horse transitions to a canter. If you listen to a horse cantering, you can hear three hoof beats instead of four, as one diagonal pair always lands together, alternating sides on each stride. 18th-century paintings of running horses always show the legs stretched out when all four hooves are off the ground, but actually the airborne phase of the canter occurs when the legs are all grouped together.

The fastest gait – the gallop – is actually just a stretched-out canter. All four hooves land at different times as the horse reaches for the longest stride length. Galloping is only possible in short bursts and generally used for escaping predators.

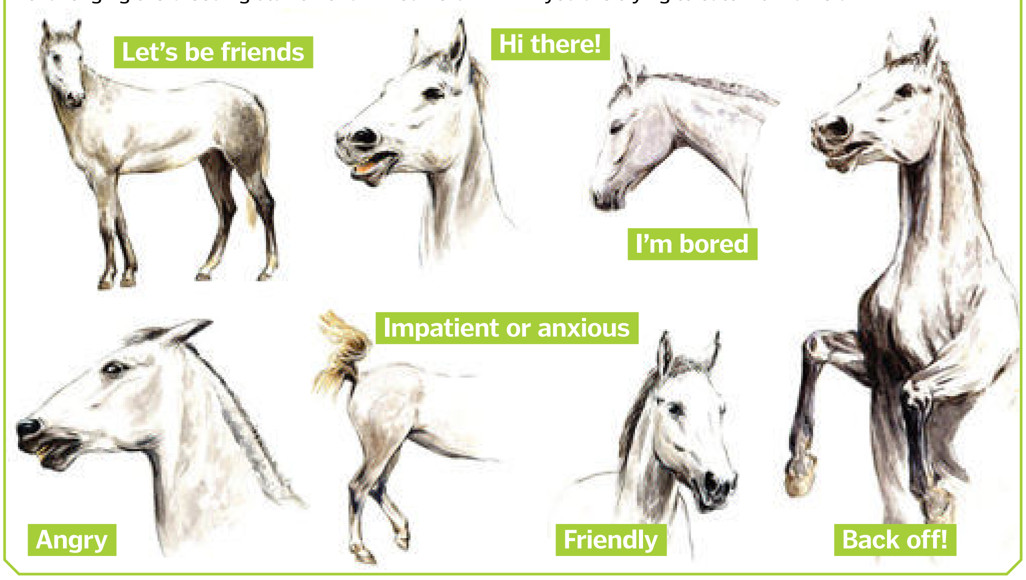


The language of the herd

Wild and feral horses typically live in herds of 10-40 animals with one of the older mares taking charge of all the major decisions. There is normally just one breeding stallion in each herd. The foals and younger horses are allowed to remain until they are two years old on average, after which both the colts (male) and fillies (female) are driven away by the lead stallion. Fillies will join another mixed herd, but the colts join a male-only bachelor herd until they are old and strong enough to try challenging the breeding stallion of a mixed herd.

Breeding and training have made domesticated horses much less skittish than their wild cousins, but most of their body language remains. Horses don't communicate with their voice much; it's mostly done with the angle of the head, the position of the ears and the movement of the eyes.

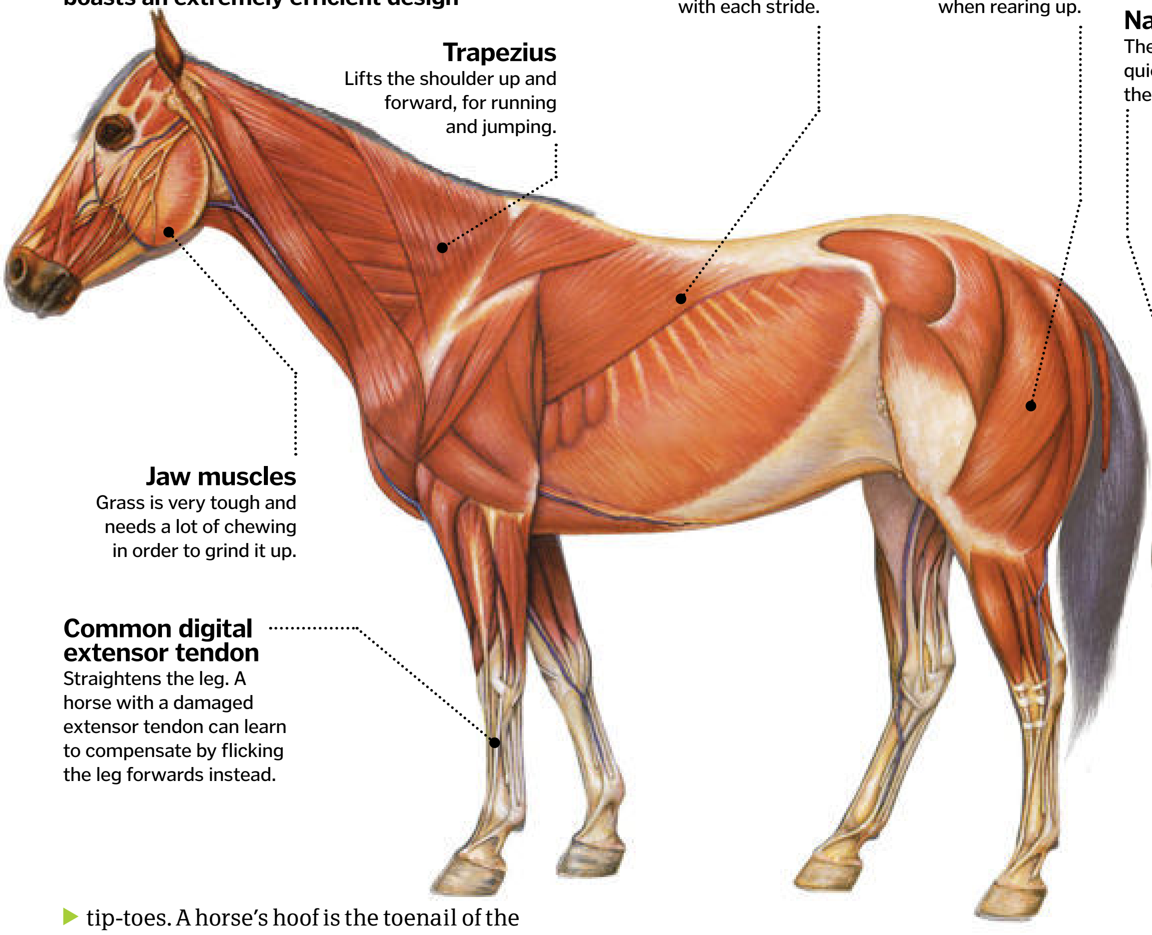
'Horse whisperers' have learned to mimic these movements to reassure a horse. Approaching a horse with your head down and angled to one side, for example, makes it much less likely to shy away if you are trying to catch it in a field.

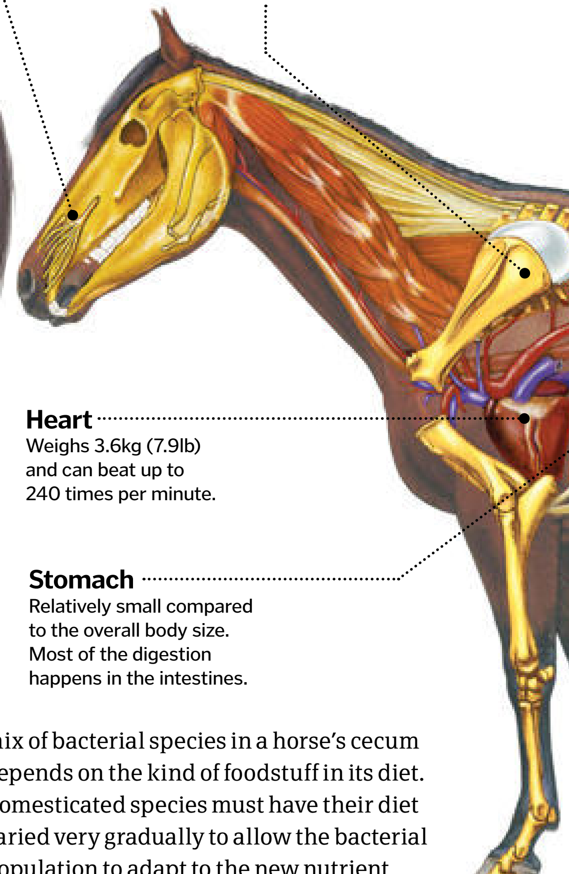


"The only true wild horse remaining today is Przewalski's horse, found solely in Mongolia"

Equine anatomy

Load bearing yet light on its feet, the horse boasts an extremely efficient design





tip-toes. A horse's hoof is the toenail of the third toe on each foot. The other toes have shrunk to almost nothing, while the third toe has become greatly enlarged. The leg joint normally called the 'knee' on a horse actually corresponds to our wrist, and the fetlock, which looks like an ankle, is in fact the knuckle joint of a finger or toe. By standing on the very tips of its toes, the horse has increased the number of different bones that contribute to the total stride length and, as evolution gradually extended the length of each one, the total length of the legs increased. Carnivores can't do this because they need to keep their claws off the ground, to keep them sharp.

Horse legs aren't just long though – they are also lightweight. Horses don't have any muscles below the knee; the joints are all moved by means of tendons and sinews, like wires in a pulley system. This keeps the heavy muscles up near the body so they don't need to be wastefully accelerated back and forth with each stride. The tradeoff is that horse legs are quite delicate. Without muscles to absorb an impact, a single kick from a rival stallion or an awkward landing on uneven ground can easily tear a tendon or break a bone. Horses use the spongy pad on the underside of their hooves (called the 'frog') to help pump blood back up the leg with each step, but even so horses have poor circulation in their lower legs and, as a result, injuries can take a long time to heal. Even with human veterinary intervention, a broken leg is usually a fatal injury for a horse.

Horses are not ruminants; they only have one stomach, compared with four for a cow. Instead, grass is digested in an enlarged chamber of the large intestine, called the cecum. This holds about 28 litres (7.4 gallons) of semi-digested grass slurry and symbiotic bacteria that break down the tough cellulose in the grass. In a cow's digestive system, the bacteria live in a chamber that sits in front of the intestine, so as they grow and multiply, the excess bacteria pass into the intestine and are themselves digested. Horses can't do this; the excess bacteria pass straight out with the droppings, wasting energy, so horses aren't such efficient grazers. The exact mix of bacterial species in a horse's cecum depends on the kind of foodstuff in its diet. Domesticated species must have their diet varied very gradually to allow the bacterial population to adapt to the new nutrient balance, otherwise they will develop colic. This gastrointestinal condition is the leading cause of death among domesticated horses. These animals are also quite vulnerable to poisoning because they can't vomit. Certain plants, such as ragwort, can cause severe liver damage. Horses will avoid fresh ragwort due to its bitter taste but can't detect it when it has been dried – during hay making, for instance.

Horses, donkeys, zebras and asses are different species, however they are all members of the same genus: Equus. They are closely related enough to be able to cross-breed, although the hybrids are nearly always infertile. The most common hybrid, a mule, is a cross between a male donkey and a female horse. Most 'wild' horses are actually feral

STRANGE BUT TRUE
CRAZY COATS

What kind of coat does the tiger horse have?

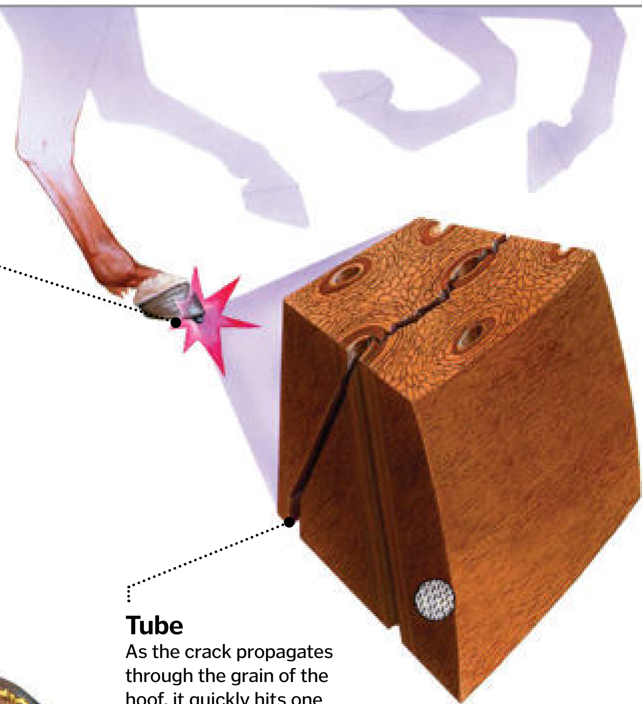
A Stripy **B** Spotted **C** Tartan

Answer:
This breed is over a thousand years old and was so named as the Chinese Royal Court used them when hunting tigers. Its coat is actually spotted, resembling a modern Appaloosa. The fine specimen pictured is Admiral's Ponca Patches – a foundation stallion of the breed Tiger horse F059.

DID YOU KNOW? *A 2009 study showed that horses can reliably count up to three, but after that they get lost*

Brace for impact

Hooves are protected from cracking by their complex structure



Impact
When a horse walks on a hard surface, small stones can create point-loading stresses on the hoof that cause it to crack.

Tube
As the crack propagates through the grain of the hoof, it quickly hits one of many microscopic tubes that run at an angle to the grain.

Layers
The wall of the tube has several concentric layers with keratin fibres running at different orientations in each one. This diffuses the energy of the crack and halts it.

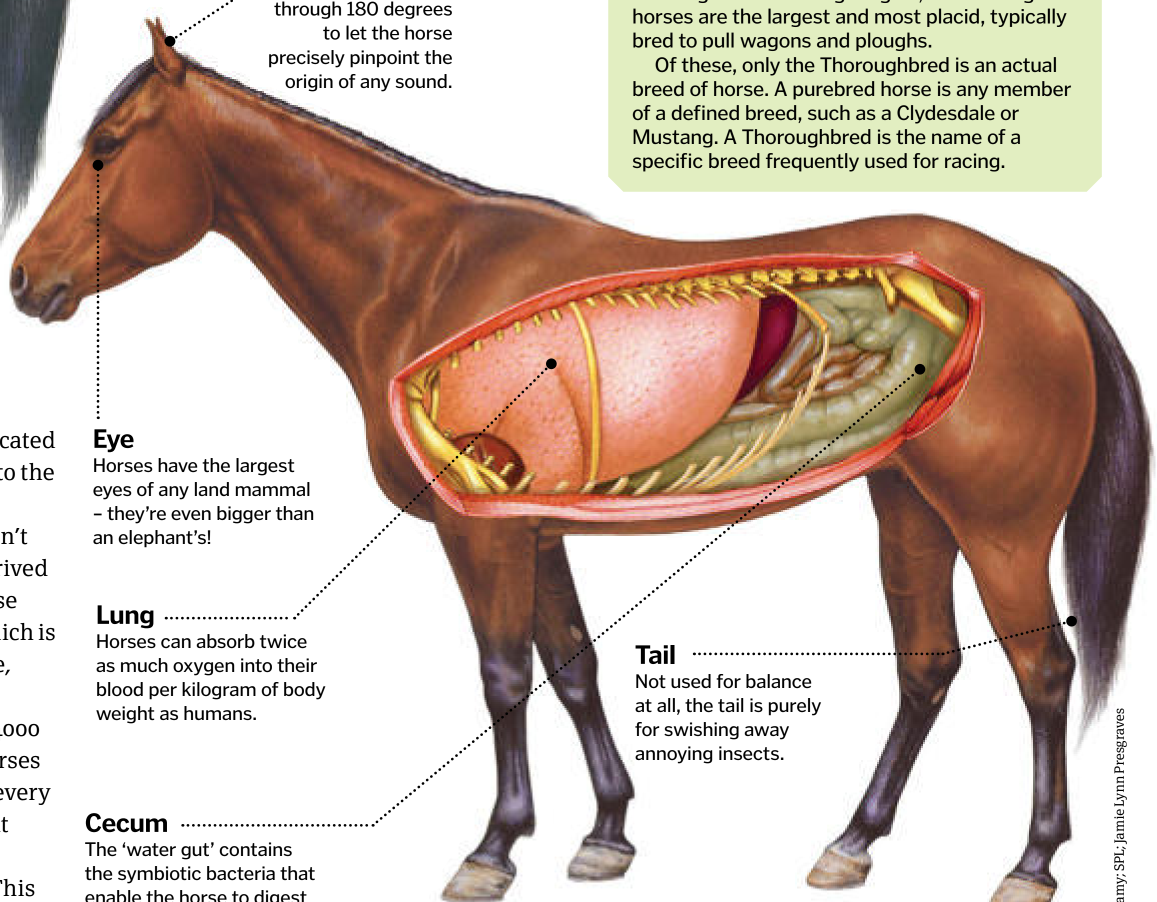
Spine
The deep vertebrae provide a strong, rigid beam for supporting the body.

Breeding matters

Modern DNA analysis has shown that all domesticated horses are descended from a single wild species. The difference between a Shetland pony and a Thoroughbred racehorse is just down to selective breeding. There are around 300 recognised breeds of horse but most of them fall into one of five categories.

Ponies are any horse under a certain height – usually 14.2 hands (147 centimetres/58 inches) at the shoulder. A cob is larger than a pony but still quite compact and solid – ideal for everyday riding. Hunters are characterised by their stamina, jumping ability and fearlessness. Thoroughbreds are larger again, while draught horses are the largest and most placid, typically bred to pull wagons and ploughs.

Of these, only the Thoroughbred is an actual breed of horse. A purebred horse is any member of a defined breed, such as a Clydesdale or Mustang. A Thoroughbred is the name of a specific breed frequently used for racing.



Ear
The ears can swivel through 180 degrees to let the horse precisely pinpoint the origin of any sound.

Eye
Horses have the largest eyes of any land mammal – they're even bigger than an elephant's!

Lung
Horses can absorb twice as much oxygen into their blood per kilogram of body weight as humans.

Cecum
The 'water gut' contains the symbiotic bacteria that enable the horse to digest the cellulose in grass.

Tail
Not used for balance at all, the tail is purely for swishing away annoying insects.

– that is, they are descended from domesticated horses that subsequently escaped back into the wild. Horses died out on the American continent about 12,000 years ago and weren't reintroduced until the Spanish settlers arrived in the 15th century. The only true wild horse remaining today is Przewalski's horse, which is a very rare subspecies of the modern horse, found solely in Mongolia.

Horses were first domesticated around 4000 BCE. Selective breeding has resulted in horses that are more docile around humans, but every horse must be trained anew to some extent before it will accept a saddle and bridle or respond to basic commands from a rider. This process is known as 'breaking in' a horse.

"The frazil ice discs will clump together when they come into contact with one another"

How do waterfalls freeze?

Some waterfalls look as if they froze mid-flow, but how is this possible?

Ice forms on still bodies of fresh water like lakes when the temperature hits 0 degrees Celsius (32 degrees Fahrenheit) or below, but the physics of freezing becomes a lot more complicated in moving water.

Waterfalls don't immediately stop flowing and freeze over when the temperature plummets to freezing point. Quite the opposite, in fact. For a start, because the moving water is constantly mixing, the entire waterfall will cool uniformly, so it will take far longer for any noticeable change of state compared with still water under the same conditions.

The temperature of the water in the river/stream and waterfall it supplies drops slightly below freezing and supercools, which causes the water molecules to slow and begin to stick together to form solid particles of frazil ice. These are tiny discs roughly one millimetre (0.04 inches) in diameter, yet this is enough to start the freezing process.

The frazil ice discs will clump together when they come into contact with one another, as well as sticking to nearby surfaces. In the case of waterfalls that flow down the face of a cliff, the discs will accumulate against the cold rock, while for a free-falling waterfall, ice will cling to the overhang.

Eventually the frazil ice will form an anchor from which it will grow and, provided the temperature of the water is sufficiently cold enough for long enough, it will create a column that runs the length of the waterfall. Over time, the river or stream will completely freeze over leaving an icy snapshot of the waterfall, eerily frozen in time.

© Thinkstock

The science of freezing

Traditionally we are taught that water freezes at 0 degrees Celsius (32 degrees Fahrenheit), but in reality it's nowhere near as simple as that. Once the correct temperature has been reached, ice crystals must nucleate for ice to form: either clinging to a central body that's another ice crystal or a foreign particle. The rate at which this happens is dependent on a number of factors, including the amount of movement in the water and wind on the surface – both of which can slow ice formation. Atmospheric pressure, a layer of insulating snow sitting on top of a thin layer of surface ice, minerals in the water and many other factors all affect the freezing process.

"The plant survives below the surface as a bulb, in a state of suspended animation"

How plants grow from bulbs

Bulbs are underground time capsules that allow plants to live through the hard times

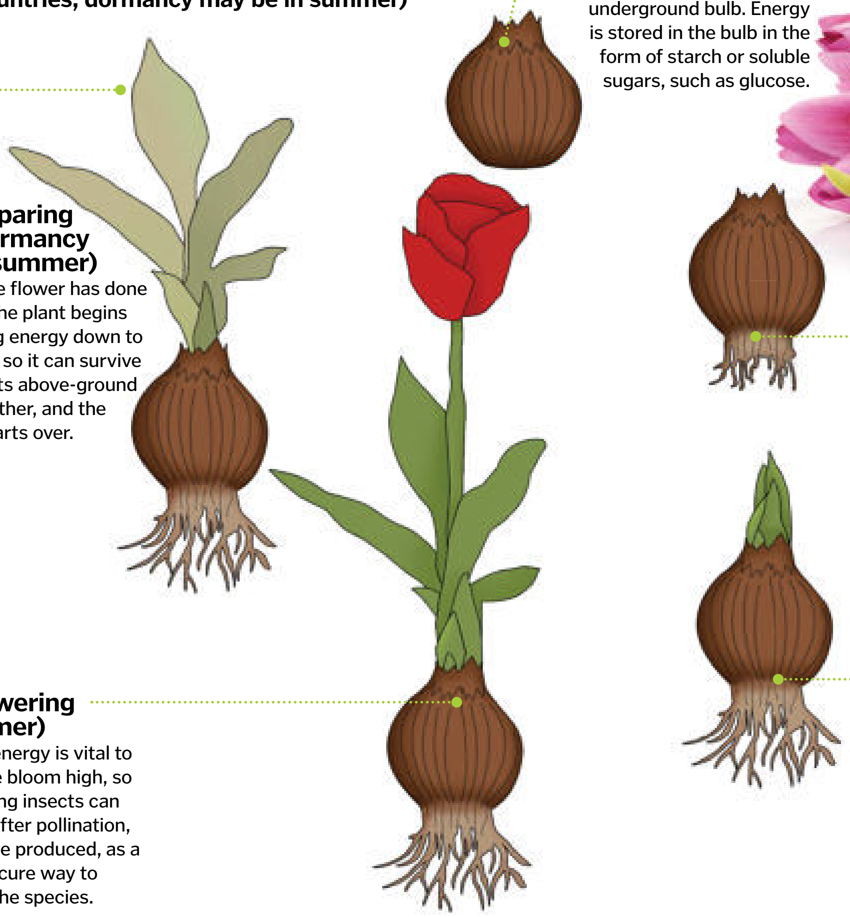
Imagine an onion. Peel away the outer layers and you'll find a central core. The onion is a typical bulb. The outer layers are swollen leaves wrapped around a short, flattened piece of underground stem. The swollen leaves protect delicate buds on the core from which new leaves, shoots and roots can grow.

For plants in colder regions, winter is the hardest season to survive. In other countries, the hot, dry summer weather is equally damaging. As the harsh season approaches, bulb-producing plants pump energy-rich starch or sugars down to these subterranean storage organs, while the above-ground parts of the plant wither. The plant then survives below the surface as a bulb, in a state of suspended animation. When better weather returns, the buds sprout and a new plant emerges.

Several bulbs might develop from the original plant, but all new plants are genetically identical to the parent. Seeds, in contrast, mix genes via sexual reproduction, producing new variations.

Life story of a bulb

Follow the life cycle of a bulb in a cold climate (in hot countries, dormancy may be in summer)



1. Dormancy (winter)
The plant survives in suspended animation as an underground bulb. Energy is stored in the bulb in the form of starch or soluble sugars, such as glucose.

2. Life returns (spring)
When the plant detects rising temperatures (or returning moisture for dry-weather bulbs), the bulb springs to life. Stored energy is used first to produce roots which can gather moisture.

3. Sprouting (early summer)
Moisture helps the leaf buds to swell, and the stem extends. Once above ground, the green parts can begin to photosynthesise, generating the energy needed for more growth.

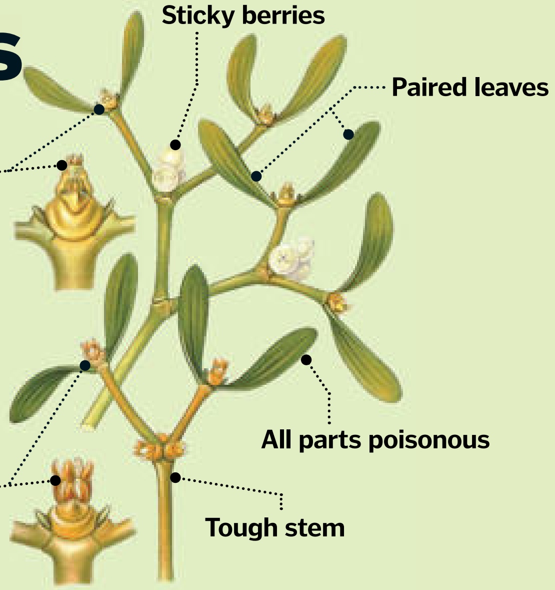
4. Flowering (summer)
All this energy is vital to raise the bloom high, so pollinating insects can find it. After pollination, seeds are produced, as a more secure way to spread the species.

5. Preparing for dormancy (late summer)
Once the flower has done its job, the plant begins pumping energy down to the bulb so it can survive winter. Its above-ground parts wither, and the cycle starts over.

How mistletoe survives

Contrary to its festive associations, mistletoe is in fact a sap-sucking vampire of the plant world

You can spot the leafy balls of mistletoe high in old apple or lime trees when they shed their leaves in autumn. In November, mistletoe produces clusters of sticky white berries with hard seeds at their core. Birds like thrushes flock to feast on these. As they eat, the sticky flesh sometimes glues a seed onto their beaks. To get rid of this encumbrance, the bird rubs against a branch and, in the process, often wedges the seed into a crevice. Next spring, the seed germinates, producing rootlets which penetrate deep into the tree trunk. There they tap into the xylem and phloem tubes which transport water and minerals around the tree. This enables mistletoe to live as a parasite, stealing everything that it needs to survive.



Plethodon glutinosus is the 'what' salamander?

A Southern fried B US dyed C Northern slimy

Answer:
Known for being extremely sticky, the northern slimy salamander – found throughout the USA – is said to be the stickiest of its kind. Its skin produces a strong mucus that can essentially glue shut the mouth of any predator that attempts to eat it!

DID YOU KNOW? The Hydromantes salamander's tongue can reach its prey in just 20 milliseconds

Ballistic tongue biology

How do some amphibians and reptiles catch bugs with projectile tongues?

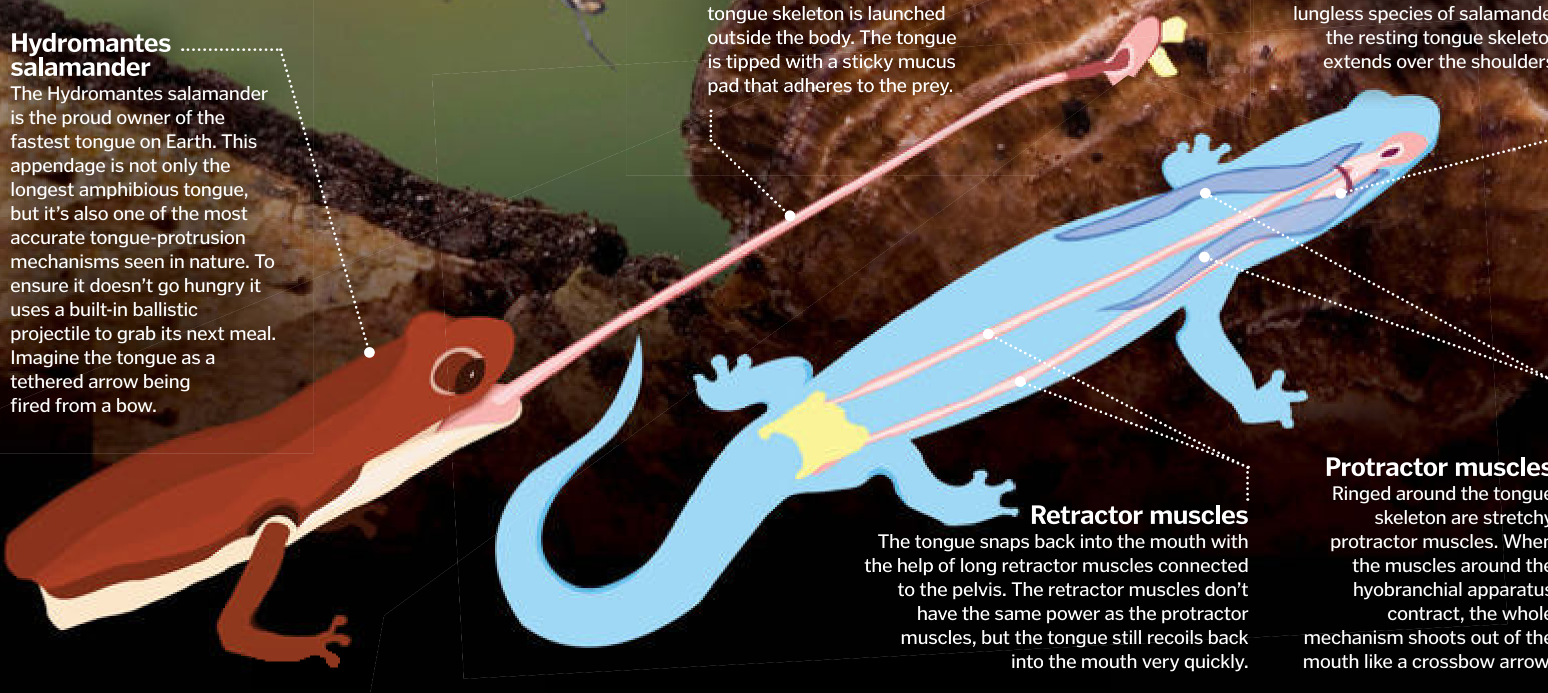
Imagine if your tongue was 80 per cent the length of your body and you could poke it out and reel it back in within 20 thousandths of a second. Well, if you're a lungless Hydromantes salamander that's one ability you already possess.

Creatures like frogs, chameleons and salamanders have a staple diet consisting mainly of insects. In order to make a quick getaway, most of these bugs have evolved sensors that detect even the slightest movements made by their would-be assassins, so the hunter must be able to get close without being detected. To help them grab a bite, some amphibians and reptiles have very long and sticky tongues – perfect for catching flighty prey without having to get so close. While most of these animals strike out using elastic recoil, Hydromantes do things a little differently...

The tip of the chameleon's ballistic tongue can accelerate up to 50 g – five times faster than a fighter jet!

The fastest tongue in the world

See how the web-toed salamander uses ballistics to fire its entire tongue skeleton out of its body



Hydromantes salamander
The Hydromantes salamander is the proud owner of the fastest tongue on Earth. This appendage is not only the longest amphibious tongue, but it's also one of the most accurate tongue-protrusion mechanisms seen in nature. To ensure it doesn't go hungry it uses a built-in ballistic projectile to grab its next meal. Imagine the tongue as a tethered arrow being fired from a bow.

Projectile
The tongue exploding from the mouth is a true projectile in the sense that the entire tongue skeleton is launched outside the body. The tongue is tipped with a sticky mucus pad that adheres to the prey.

Tongue skeleton
The tongue consists of a bony skeleton surrounded by protractor muscles that store elastic energy. While the tongue skeletons of other amphibians are found in the base of the mouth, in this lungless species of salamander the resting tongue skeleton extends over the shoulders.

Retractor muscles
The tongue snaps back into the mouth with the help of long retractor muscles connected to the pelvis. The retractor muscles don't have the same power as the protractor muscles, but the tongue still recoils back into the mouth very quickly.

Protractor muscles
Ringed around the tongue skeleton are stretchy protractor muscles. When the muscles around the hyobranchial apparatus contract, the whole mechanism shoots out of the mouth like a crossbow arrow.

"The volcano remains active and America's second-most dangerous"

The eruption of Mount St Helens

Discover how a mountain lost its top in America's most economically destructive volcanic eruption

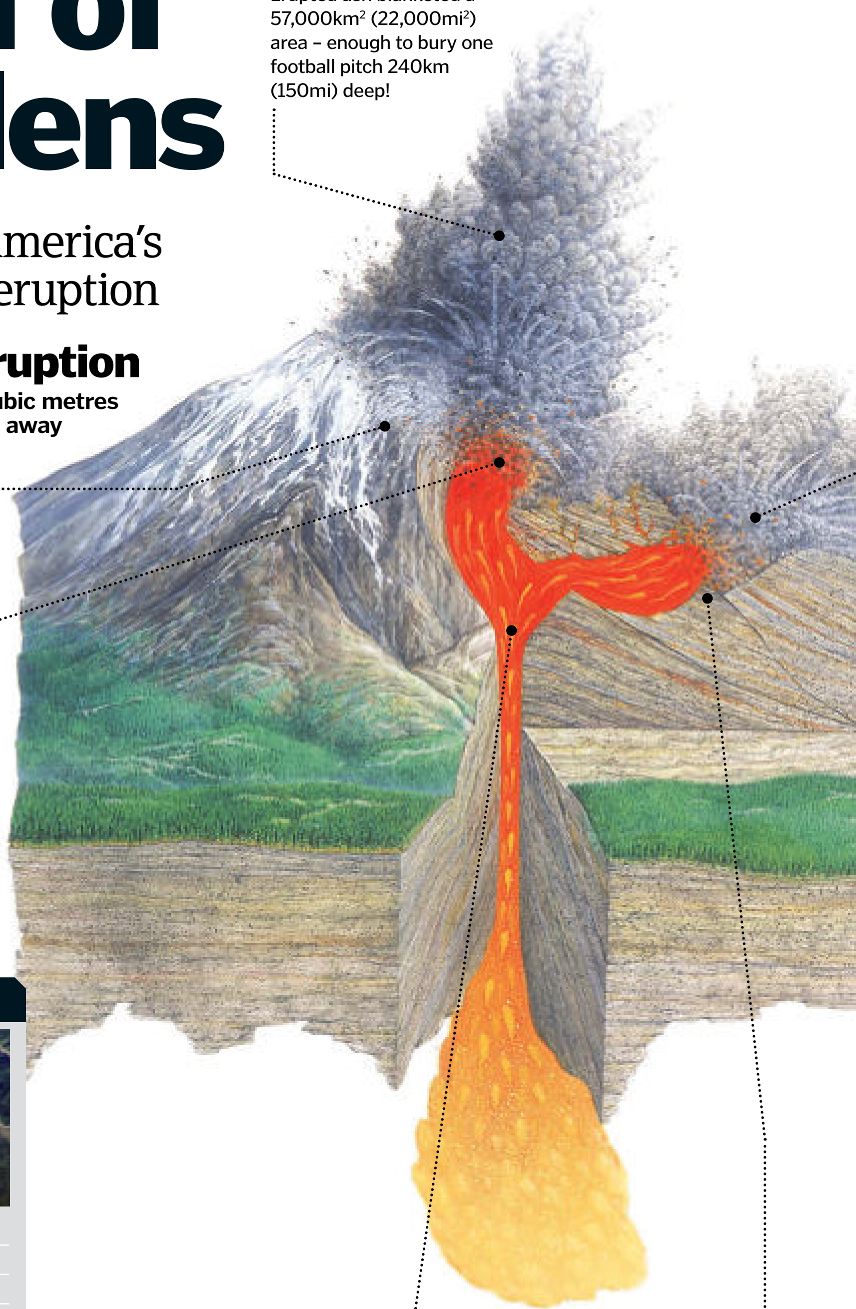
Mount St Helens blew off its summit in May 1980 with the energy of 20,000 Hiroshima-size atomic bombs. The resulting rock blast and mudslides killed 57 people and around 7,000 large animals, engulfed 200 houses, choked rivers, buried highways and flattened trees like matchsticks. Fine-grained ash closed nearby airports for up to two weeks, grounding thousands of flights. The damage cost $1.1 billion to repair.

The volcano remains active and America's second-most dangerous. It sits on the Ring of Fire – a 40,000-kilometre (25,000-mile) horseshoe of volcanoes circling the Pacific Ocean. Beneath Mount St Helens, two of the massive rock plates that form the Earth's crust are colliding; the oceanic Juan de Fuca Plate is sliding beneath the continental North American Plate. As the ocean plate grinds down into the Earth's crust, water is released. The water helps to melt the overlying hot rock into magma, which erupts through the brittle crust. The old North American crust contains lots of silica, which makes the magma sticky.

Gas builds up in this thick magma until it violently erupts with gas, rock and steam. This debris piles up into steep-sided volcanoes. Before the 1980 eruption, Mount St Helens was 3,000 metres (1,000 feet) tall and had been dormant since 1857. The volcano reawakened in March 1980 with a series of tremors and a growing bulge on its north side. A week before the volcano, the bulge grew two metres (6.6 feet) daily. After the eruption, Mount St Helens had shrunk by about 400 metres (1,300 feet).

Inside the eruption

Learn how 2.8 billion cubic metres of mountain was blown away



Ash eruption
Erupted ash blanketed a 57,000km² (22,000mi²) area – enough to bury one football pitch 240km (150mi) deep!

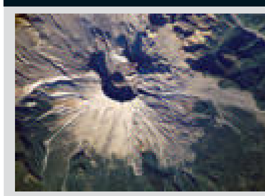
Summit lowered
The summit of Mount St Helens was reduced by about 400m (1,312ft) due to the eruption.

Uncorking
The debris avalanche allowed high-pressure steam in rocks and fissures, plus gas dissolved in the cryptodome, to expand and explode.

Cryptodome
A dome of sticky magma built up beneath the mountain, making the surface bulge and destabilising the rocks above.

Rotational slide
The volcano's north flank collapsed in 15 seconds as three blocks of rock slumped downhill as a huge debris avalanche.

The statistics…



Mount St Helens

Location: Washington, USA
Height: 2,600m (8,530ft)
Years of activity: 40,000
Last major eruption: May 1980
Type of formation: Subduction-related
Last eruption: January 2008

The 1980 eruption

Find out how this Washington mountain exploded over a day

March-May 1980
Bulge
Up to 30 mini-earthquakes shake the mountain daily and the volcano's north slope begins to bulge.

18 May 8.32am
Mega-quake strikes
20 seconds after 8.32am, a 5.1-magnitude earthquake rumbles 1.6km (a mile) beneath the volcano.

8.32am
Summit collapses
Ten seconds later the volcano's bulging north flank slides downhill as a gigantic rock avalanche that moves at up to 69m (226ft) per second.

8.35am
Sideways blast
Pressurised superheated gas and steam explode sideways, like champagne from an uncorked bottle, after the heavy overlying rock slides away.

STRANGE BUT TRUE
HELEN WHO?

Who is Mount St Helens named after?

A Lord Helen **B** Baron St Helens **C** Mr Mount

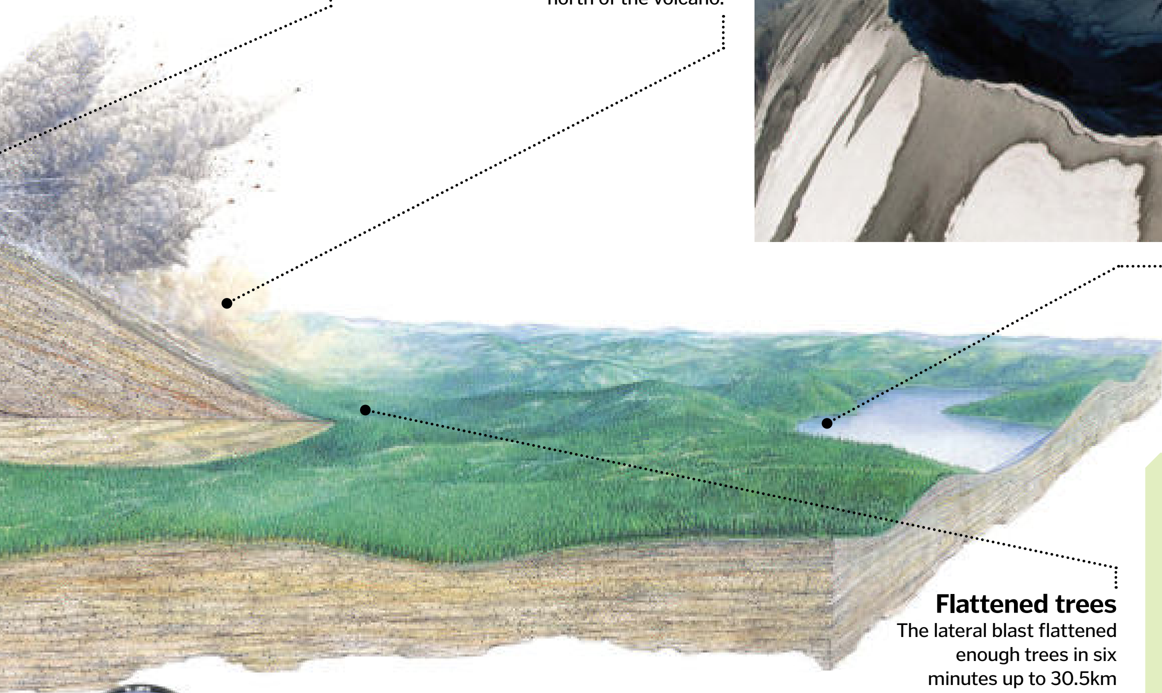
Answer:
Mount St Helens is named after Alleyne Fitzherbert (Baron St Helens) – a British ambassador to Spain. The diplomat was a close friend of explorer Captain George Vancouver, who gave this mountain its name during a surveying expedition from 1791-95.

DID YOU KNOW? *An eruption four times larger than the 1980 blast caused Native Americans to flee 3,600 years ago*


The majority of Mount St Helens is less than 3,000 years old

Crater
The eruption and sliding blocks created an amphitheatre-shaped crater 1.5 x 3.2km (1 x 2mi) wide, open to the north.

Lateral blast
A hot blast of rock, ash and gas obliterated the landscape in a 600km² (230mi²), fan-shaped zone north of the volcano.



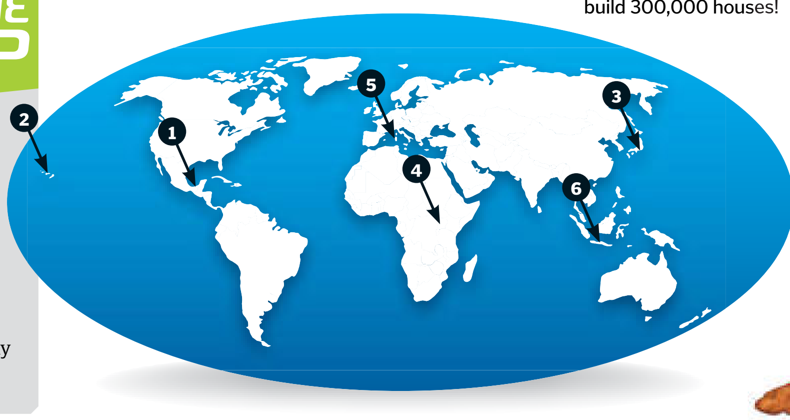
Lahars
Pyroclastic mudflows called lahars filled local rivers, killing 12 million salmon, damaging 27 bridges and forcing 31 ships to remain in river ports.

Flattened trees
The lateral blast flattened enough trees in six minutes up to 30.5km (19mi) from the volcano to build 300,000 houses!

ON THE MAP

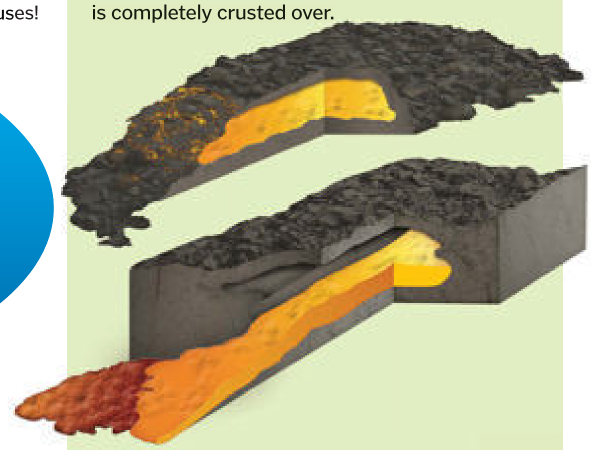
Six major active volcanoes around the world today

1. Citlaltépetl, Veracruz-Puebla, Mexico
2. Mauna Loa, Hawaii, USA
3. Fuji, Honshu, Japan
4. Nyamulagira, DR Congo
5. Vesuvius, Campania, Italy
6. Tambor, Sumbawa, Indonesia



What are lava tubes?

Lava tube
A lava tube forms when treacle-like basaltic lava flows downhill from a volcano along a channel like a river. Over time, a solid rock crust forms on the channel's surface as the 1,000-degree-Celsius (1,832-degree-Fahrenheit) lava cools when it's exposed to air. The lava within can remain hot and runny for tens of kilometres even when the tube is completely crusted over.



Pahoehoe
The ropey-looking lava emerging from the tube is called pahoehoe – a Hawaiian word for flows that form bizarre shapes. The tube is only partly filled by lava: the lava's heat downcuts through the channel bed. Superheated air and gas fill the space above the lava and re-melt the ceiling to create soda straw stalagmites – formations which are only found in lava tubes.

8.42am
Ash eruption
A huge mushroom cloud of ash and steam shoots more than 19km (12mi) into the atmosphere.

8.50am
Mudflows
The rock avalanche mixes with water to form mudflows in the nearby Toutle River, filling the valley up to 180m (600ft) deep with debris.

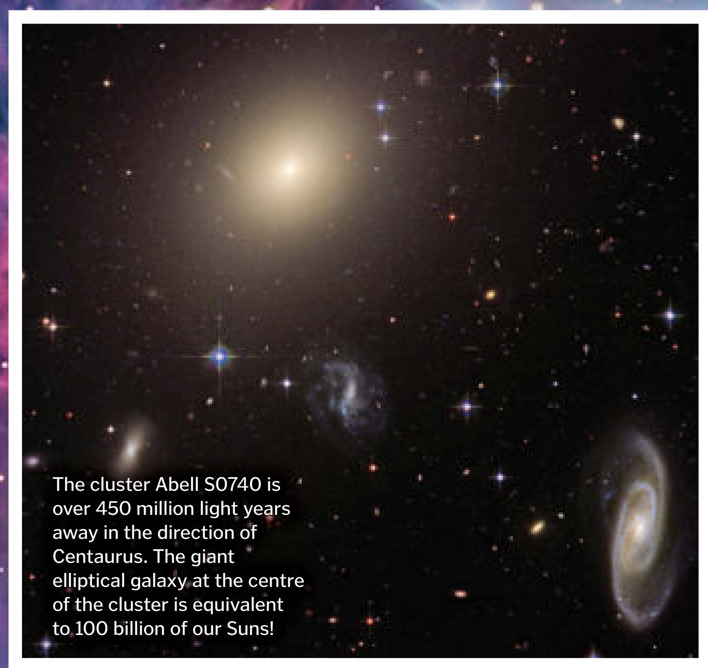
12.00pm
Pyroclastic flows
Glowing clouds of volcanic rock, ash and gases froth over the crater rim like a pot of oatmeal boiling over.

1.00pm
Aftermath
Streetlights turn on during the afternoon in parts of eastern Washington as the dense ash cloud turns daylight into darkness.

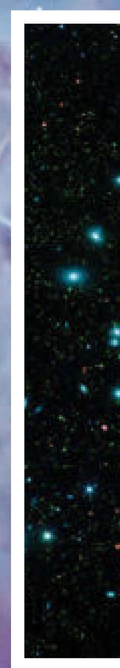
SUPER GALAXIES

Galaxy clusters and superclusters are the largest structures in the universe, but how do they influence galaxies like our own?

Hubble captured this image of galaxy cluster MACS J1206.2-0847, 4.5 billion light years from Earth. Galaxy clusters help scientists study the gravitational effects of dark matter



The cluster Abell S0740 is over 450 million light years away in the direction of Centaurus. The giant elliptical galaxy at the centre of the cluster is equivalent to 100 billion of our Suns!



THE STATS
VIRGO CLUSTER

PROPORTION OF CLUSTER MASS IN INTRACLUSTER GAS **10%**
INTRACLUSTER GAS TEMPERATURE (°C) **10mn-100mn**
DIAMETER (LY) **~15mn**
NUMBER OF GALAXIES **~1,300**
PROPORTION OF CLUSTER MASS IN DARK MATTER **85%**

DID YOU KNOW? Curiously the tenth-brightest galaxy in rich clusters always has roughly the same true brightness

Enter the void

Between the filaments and sheets of supergalaxies lie enormous gulfs of space known as voids. Ranging in size between 40 million and 500 million light years, they are defined by a lack of clusters or superclusters, but are still home to a few scattered 'field galaxies'. Along with superclusters, they were identified for the first time in the Harvard-Smithsonian Center for Astrophysics (CfA) Galaxy Redshift Survey, which attempted to map out the large-scale universe for the first time from 1977–82. Today, voids are thought to have arisen as a result of pressure waves called baryon acoustic oscillations (BAOs) that rippled through the fireball of the early universe and helped concentrate both dark and baryonic (luminous) matter in certain regions, while leaving others empty. The closest void to Earth – known as the Local Void – is around 200 million light years across, with the Local Sheet (including the Virgo Cluster and our own small Local Group of galaxies) defining one of its edges.


The Coma Cluster's centre is dominated by two large elliptical galaxies: NGC 4889 and NGC 4874. This shot was captured by the Spitzer Space Telescope

Our universe is a big place – looking out from Earth, we can see a huge sphere of space stretching for billions of light years in every direction, its darkness illuminated by the glow of distant galaxies like our own. But the distribution of galaxies is not random – while roughly half are lone wanderers called field galaxies, the rest (including our own Milky Way) are gathered together in galaxy clusters, or 'supergalaxies' – conglomerations that may contain anything from a few dozen to a few thousand separate galaxies.

Supergalaxies essentially form the large-scale structure of the universe. Merging together at their edges to form even larger superclusters, they fill the cosmos with a network of thread-like filaments and thin sheets, surrounding enormous and apparently empty dark areas called voids. Their distribution gives us clues to the way in which the cosmos developed, while the close encounters that occur within them are thought to play a vital role in the evolution of galaxies. They can even create an entirely new class of galaxy – monstrous giant ellipticals that are the largest star systems known, with up to 200 times the mass of the Milky Way.

The enormous mass of galaxies makes them naturally gregarious – their gravity extends across millions of light years of surrounding space, influencing the motion of other galaxies passing nearby and, if conditions are right, pulling them into orbit. Large galaxies like the Milky Way and the nearby Andromeda spiral move through space with a halo of smaller galaxies in orbit around them. Close encounters or collisions with these satellite galaxies are common on a cosmic timescale, and can result in the smaller galaxy being completely cannibalised and absorbed. Big galaxies also influence each other over larger distances – for instance, Andromeda and the Milky Way are being pulled towards each other and are doomed to collide in around 4 billion years' time.

On the largest scales, gravitational attraction also plays a key role in the evolution of supergalaxies, but it is not enough to explain their concentration in filaments and sheets in the first place. In the 13.7 billion years since the universe was born from the Big Bang, there has simply not been enough time for galaxies to come together under the influence of gravity alone. Instead, astronomers think that supergalaxies were born out of denser knots of matter in a universe that had already separated into large regions of differing density in the immediate aftermath of the Big Bang (see the 'Enter the void' boxout).

The term 'supergalaxy' is quite loosely defined – some astronomers use it to refer to galaxy clusters on all scales, while others reserve it for only the richest and densest, classifying less impressive gatherings as mere galaxy groups. Our own Local Group, for ▶


Located about 450 million light years from Earth, Arp 272 is a collision between two spiral galaxies – NGC 6050 and IC 1179 – which may indicate the eventual fate of the Milky Way and Andromeda galaxies

"Detectors have revealed that supergalaxies are among the most powerful X-ray sources in space"

instance, contains just the Milky Way and Andromeda galaxies, along with the smaller Triangulum spiral and several dozen much smaller dwarf systems, scattered across about 10 million light years of space. The far more impressive Virgo Cluster – some 60 million light years from Earth – incorporates around 1,300 galaxies including dozens of large spirals and ellipticals, yet it occupies a surprisingly similar diameter of just 15 million light years across. Curiously, even the most impressive and distant supergalaxies, which can contain as many as 3,000 galaxies, have similar diameters of 10-30 million light years.

Inside a supergalaxy, each individual member follows its own unique path through space, however this path betrays the influence of its neighbours. The members of a cluster are bound together in orbit around a common centre of gravity, and astronomers can measure both their speed and direction of travel by analysing the rainbow-like spectra of their light. This provides a good way of testing whether a galaxy is actually a true member of a cluster, or just a field galaxy that happens to be passing through.

A sense of scale

Galaxies like our Milky Way are so big that light takes 100,000 years to cross it, travelling at 300,000 kilometres (186,000 miles) per second. The commonly used measure of distance – a light year – is equivalent to 9.5 trillion kilometres (5.9 trillion miles); with figures this large, it's little wonder astronomers prefer not to use everyday units! In a supergalaxy, large galaxies are separated by a couple of million light years at most – just a few times their own diameter. In contrast, light takes little more than a second to travel between the Moon and Earth, and about 500 seconds to arrive at Earth from the Sun. To put it another way, if our world was a one-millimetre (0.04-inch) dot, the Moon would be just three centimetres (1.2 inches) away, but our galaxy would stretch as far as the Sun, and the Local Group supergalaxy would be about the size of our Solar System out to the orbit of Neptune.

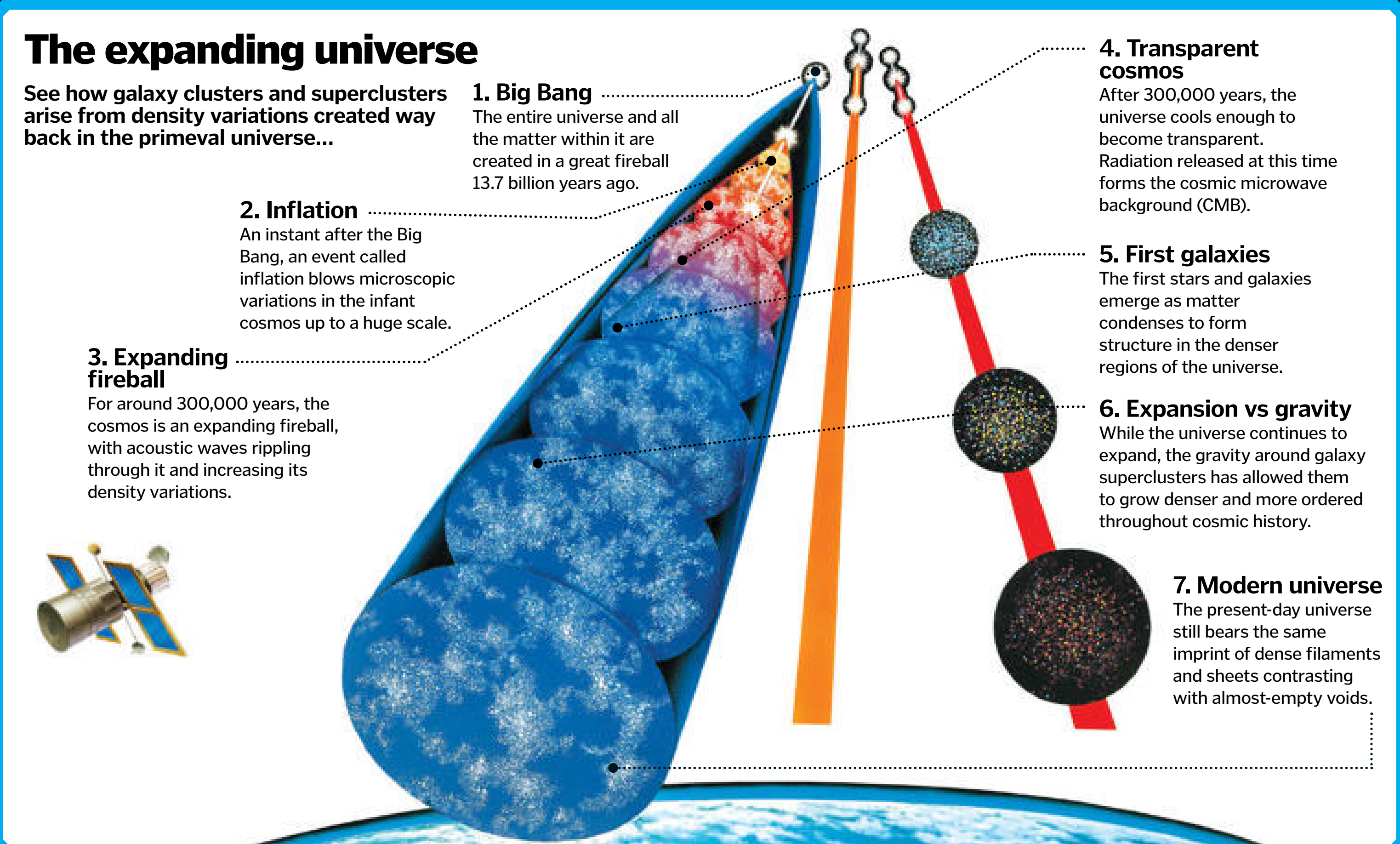
Measuring the orbits of individual galaxies, especially on the supergalaxy's outer edges, can also provide useful data like the cluster's overall mass. This led, in the Thirties, to the discovery that supergalaxies contain far more mass than their luminous contents suggest – one of the first hints that a large proportion of cosmic mass is mysterious dark matter.

Individual orbits also help to distinguish between supergalaxies whose members have been locked in their gravitational waltz for some considerable time, and those whose tracks through space are more mixed – perhaps as a result of collisions and mergers. The powerful gravity of supergalaxies draws them toward one another, leading to epic cosmic impacts or the formation of extended superclusters (the Virgo Cluster, for example, forms the core of a 'Local Supercluster' that stretches as far as our own Local Group).

Since the Fifties, detectors and telescopes sent into space have revealed supergalaxies are among the most powerful X-ray sources in the cosmos. These high-energy rays are produced by huge quantities of gas heated to millions of degrees, lying in the heart of supergalaxies. The distribution of this intracluster gas is patchy in smaller clusters, but smoother in the larger ones, and often centred on one or more giant elliptical galaxies at the cluster's heart. Intracluster gas is thought to outweigh all the other luminous material in a supergalaxy by a factor of 2:1 (though this is still not enough to resolve the dark matter problem).

The expanding universe

See how galaxy clusters and superclusters arise from density variations created way back in the primeval universe…



STRANGE BUT TRUE
PULLING POWER

What exerts the biggest pull on the Milky Way?

A Virgo Cluster **B** The Sun **C** Norma Cluster

Answer:
The Norma Cluster lies at the centre of a huge mass concentration called the Great Attractor, which is disrupting the general expansion of the universe and pulling galaxies towards it over millions of light years. The Milky Way is just one of those affected.

DID YOU KNOW? *Giant elliptical galaxy M87, in the Virgo Cluster, weighs about 200 times as much as the Milky Way*

The crowded conditions inside supergalaxies mean that even their larger individual members may be separated by just a few times their own diameter, or even less. As a result, spectacular intergalactic close encounters and even head-on collisions are common. Close encounters typically unleash powerful tidal forces that may cause spiral arms to unwind into long tails stretching across space, or create shockwaves that trigger new waves of star birth, resulting in a variety of 'peculiar' galaxies, each unique in appearance.

In a direct collision between galaxies, individual stars are usually spread out so widely that they survive unharmed. However, most galaxies are also filled with huge clouds of raw stellar material – a mix of light hydrogen and helium gas and dust, known as the interstellar medium (ISM). As these ISM clouds plough into each other, the shock can trigger spectacular 'starburst' events in which the rate of star birth in a galaxy can be boosted by up to a millionfold. Heated to great temperatures, some of the ISM gains enough energy to escape the galaxies' gravity entirely, becoming intracluster gas. Here, it is soon supplemented as short-lived heavyweight stars born in the starburst die in spectacular supernova explosions and scatter their heavier elements across interstellar and intergalactic space.

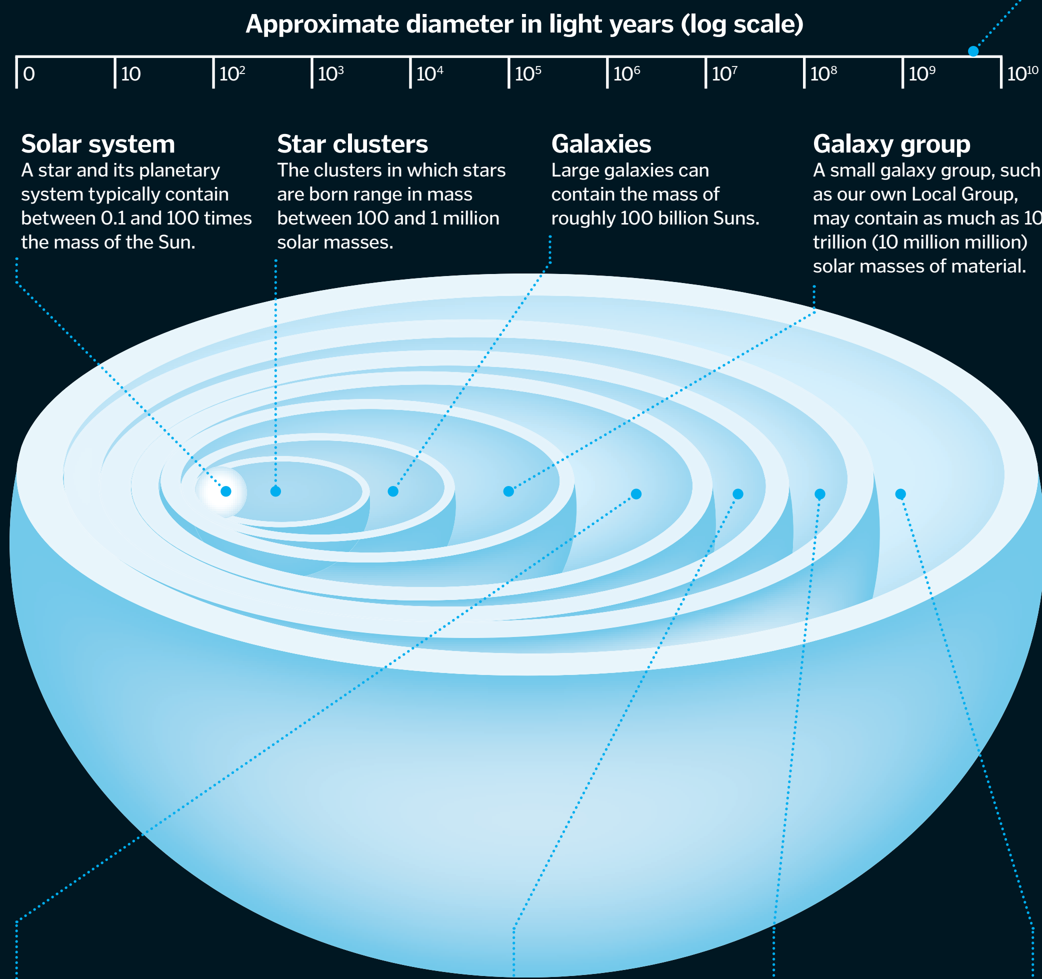
Experts think that such collisions are responsible for generating most of the intracluster gas that lies between galaxies. They also help change the structure of galaxies themselves, using up or driving out the raw materials of star formation, while at the same time mixing up the orbits of surviving stars into a chaotic melee. The end result is that a gas-rich system such as an irregular or spiral galaxy may ultimately be transformed into a spheroidal or elliptical galaxy – a system devoid of ISM or young stars, and dominated by older stars whose overlapping orbits form a more or less structureless ball or ellipse.

This, it seems, is the reason why large elliptical galaxies are only found in the heart of rich supergalaxies. A result of repeated mergers, these galactic monsters may weigh as much as several hundred Milky Ways and contain trillions of stars. They give their origins away through the presence of huge numbers of 'globular' star clusters cannibalised from the galaxies that they have subsumed in the past. Sitting at the centre of a cosmic web, they exert their influence over tens of millions of light years, ruling over an entire supercluster.

Universe in a nutshell

This diagram compares the masses and diameters involved in the scale of the cosmos from planetary systems like our own right up to the visible universe

Logarithmic scale
This shows the different sizes of cosmic objects, compressing the larger scales using powers of ten.



Solar system
A star and its planetary system typically contain between 0.1 and 100 times the mass of the Sun.

Star clusters
The clusters in which stars are born range in mass between 100 and 1 million solar masses.

Galaxies
Large galaxies can contain the mass of roughly 100 billion Suns.

Galaxy group
A small galaxy group, such as our own Local Group, may contain as much as 10 trillion (10 million million) solar masses of material.

Supergalaxy
Larger galaxy clusters, or supergalaxies, have masses equivalent to 1 quadrillion Suns (that's 1 followed by 24 zeroes!)

Supercluster
Superclusters formed from the conglomeration of galaxy clusters can have masses of 10 quadrillion solar masses.

Sheets and voids
The largest structures in the universe, the galactic sheets around the edges of voids weigh as much as 100 million billion Suns.

The observable universe
The sum of material in the visible universe has an estimated mass of 10,000 billion billion Suns.

Shining a light on dark matter

In 1932, Swiss-American astronomer Fritz Zwicky made the first attempt to measure the motion of individual galaxies within a supergalaxy, targeting the rich Coma Cluster some 320 million light years from Earth. When he discovered that the motion of the galaxies was much faster than the cluster's visible matter could account for, he coined the phrase 'dunkle materie' (dark matter) to describe it. Zwicky believed that his dark matter outweighed luminous material in the Coma Cluster by around 400 times, but the discovery of intracluster gas, along with improved measurements, now suggests that dark matter accounts for approximately 85 per cent of the supergalaxy's mass.

What's more, dark matter seems to be widespread throughout the universe, concentrated in and around individual galaxies and clusters. This mysterious substance is not only dark but entirely transparent in all radiations, and astronomers can only measure its presence through the gravity it exerts. Perhaps the cleverest of these techniques uses gravitational lensing – the way in which large concentrations of mass distort the path of light from more distant objects beyond them. By measuring such distortions, scientists can estimate both the mass and distribution of dark matter within them, confirming that it tends to concentrate around individual galaxies.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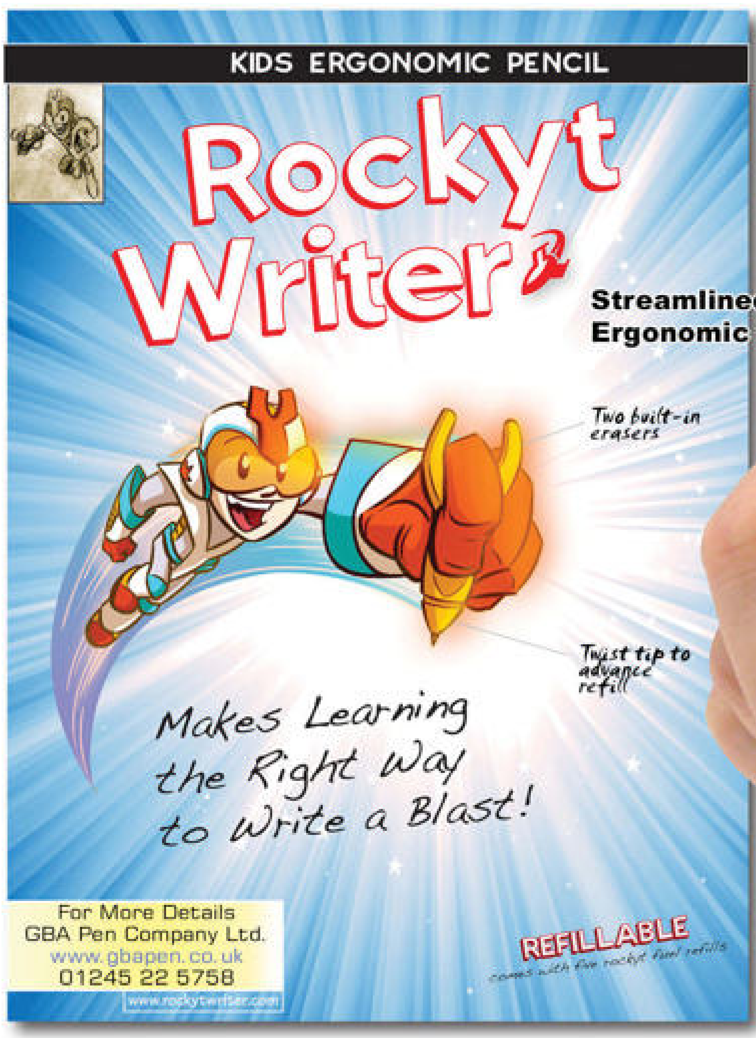
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RECORD BREAKERS
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20,000m

TALLEST DUST DEVIL

The tallest dust devil to be imaged in high resolution so far by the Mars Reconnaissance Orbiter measured a whopping 20 kilometres (12.4 miles) in height!

DID YOU KNOW? *Mars has an axial tilt of 25.2 degrees, granting it regular seasons like on Earth*

Amazing Martian weather

From dust devils to carbon dioxide ice fans, Mars sees some weird phenomena

Martian dust devils are one example of the unusual weather found on the Red Planet. A dust devil is a 'skinny' whirlwind that on Earth forms when hot air near the surface rises rapidly through a pocket of cooler, lower-pressure air and begins to rotate. This creates a spinning column of air – typically 10-50 metres (33-164 feet) in height – that has enough energy to suck up surface dust.

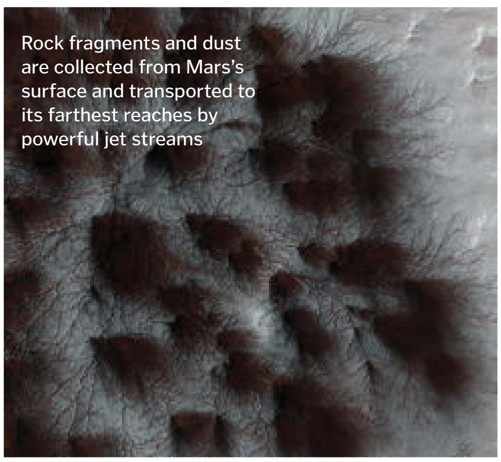
Martian dust devils are in a different league to those on Earth. Typically 50 times as wide and often several kilometres high – as well as boasting intense rotational energy that can suck up vast quantities of dust and rocks – dust devils on Mars are more akin to super-tornadoes. Indeed, they are so powerful that they leave a visible trail of chaos in their wake, in the form of huge snake-like streaks.

Talking of dust, the dust storms on Mars have the ability to shroud the entire planet in a violent gauze of particulate matter moving at 145 kilometres (90 miles) per hour-plus that can reduce visibility to less than five per cent of that under normal conditions.

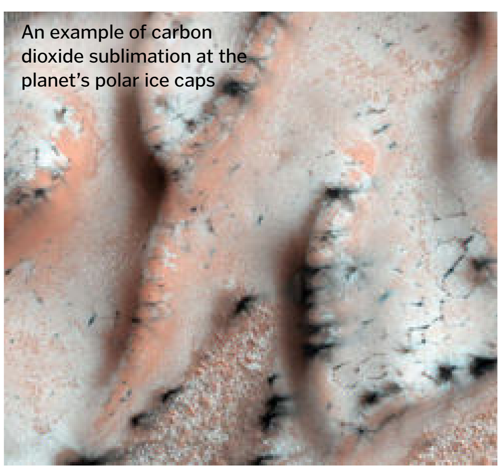
These epic storms form in the planet's southern hemisphere during the spring and summer seasons. Activity is first heavily localised, however when the amount of carried dust reaches a critical quantity, the storm rapidly intensifies and spreads, carried to the far-flung reaches of the Red Planet through strong jet streams at speeds commonly in excess of 100 metres (328 feet) per second.

Another prominent feature on Mars that is driven by its seasons is the sublimation (rapid vaporisation) of carbon dioxide ice near the planet's surface. This occurs when Mars's seasonal winter caps of frozen carbon dioxide are quickly heated and transformed into vapour in spring. The gaseous CO_2 then escapes through gaps in the ice, carrying dust with it, and is spread by local winds over the surface, often into distinctive fan shapes.

Mars also has clouds like Earth. These clouds, however, generally form much higher in the atmosphere than ours (ie 80-100 kilometres/50-62 miles up) and are made of carbon dioxide. They are also very faint, resembling mesopheric clouds, and can only form around minuscule grains blown high into the atmosphere during dust storms.



Rock fragments and dust are collected from Mars's surface and transported to its farthest reaches by powerful jet streams



An example of carbon dioxide sublimation at the planet's polar ice caps

Martian dust devils cruise across the planet's surface, leaving a serpentine tail of dust and rock in their wake

"Across its trailing hemisphere are wispy features that were thought to be remnants of ice volcanism"

Dione explained

Discover the amazing features that make the 15th-largest moon in the Solar System unique

Of the 62 known moons of Saturn, Dione is only the fourth largest and yet one of the most intriguing. It was discovered by Giovanni Cassini in 1684, after whom the Cassini spacecraft that is currently in orbit around the Saturnian system was named.

Dione is largely made of rock and ice, with its surface strewn with impact craters ranging in size from just a few hundred metres across to others over 100 kilometres (62 miles) wide.

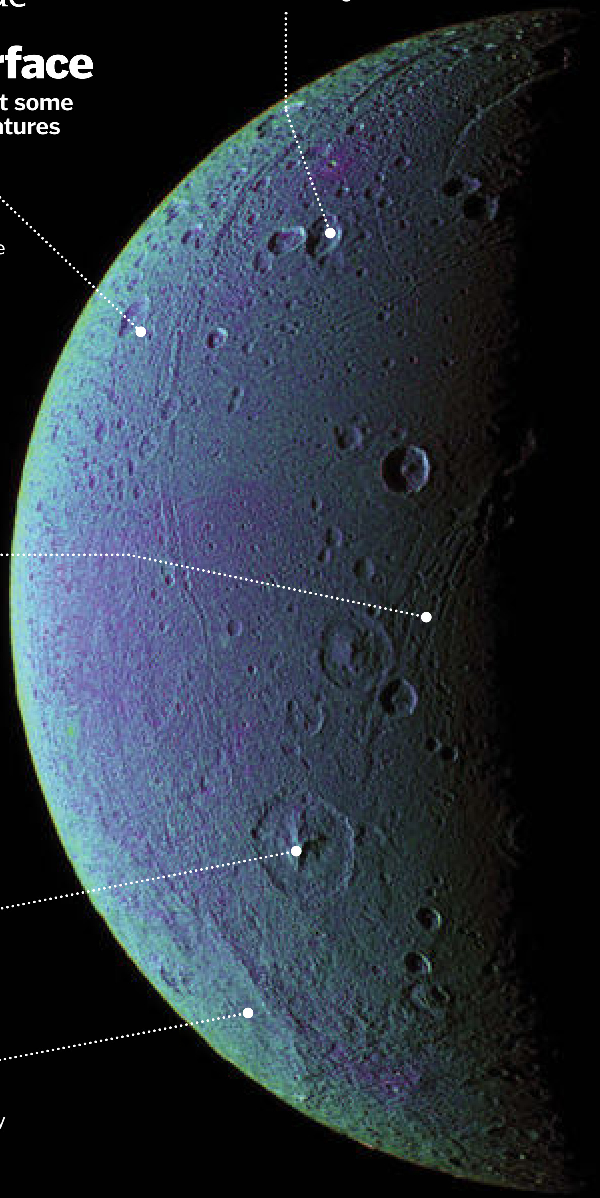
It is tidally locked to Saturn, so the same face always points towards the gas giant, though most of its craters are found on its trailing hemisphere relative to its orbital path. This has led scientists to speculate that past impact events have spun the moon 180 degrees. Dione is also bombarded with dust from Saturn's rings, creating a fine icy powder.

Dione was first visited in 1980 by Voyager 1, which returned unusual images of its surface. Across its trailing hemisphere are wispy features that were at first thought to be remnants of ice volcanism. Observations by the Cassini spacecraft in 2004, however, revealed these features to be ice cliffs formed from tectonic activity. Some of these cliffs rise hundreds of metres high. The walls of the cliffs are bright due to water-ice being exposed.

While it may have once been geologically active, Dione bears little sign of any noticeable atmosphere save for a thin layer of molecular oxygen ions. This is referred to as an exosphere rather than a proper atmosphere. Regardless, it is the icy cliffs and cracks of this barren body that are of most interest, revealing some key information about how moons form.

On the surface

Take a closer look at some of Dione's major features



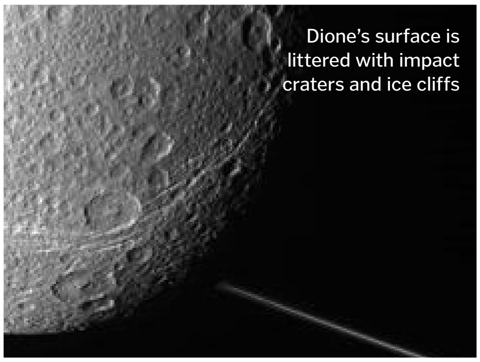
Craters
Dione's leading hemisphere, shown here, is bombarded more regularly than the trailing hemisphere, forming craters.

Cassini
The Cassini spacecraft caught this view of Dione on Christmas Eve in 2005 from a distance of 151,000km (94,000mi).

Chasms
Long chasms, some with icy walls stretching hundreds of metres high, scar the surface.

Rotation
An impact causing a crater just 35km (22mi) wide might have been enough to spin Dione.

Flat
Aside from chasms and craters Dione is relatively flat, suggesting its icy crust is quite weak.



Dione's surface is littered with impact craters and ice cliffs

Imaging Dione

In this image tectonic faults and craters on Dione are clearly visible. The odd colouring is due to the type of image processing that was used to make Dione's features more visible. Ultraviolet, green and infrared images were combined onto a black-and-white image of the moon to create this enhanced colour view. The colours highlight particular features, but the reason for the changes in colour is not known. It may indicate that the surface composition varies greatly across Dione. The image is looking towards the satellite's leading hemisphere – the one that points forwards in its orbital path around Saturn. North is up in this composite shot.

1. BRIGHTEST

Surt
Io's Surt volcano produced the Solar System's most energetic and brightest eruption ever when the Keck Observatory spotted it back in 2001.

2. HIGHEST

Olympus Mons
This massive Martian volcano stands three times taller than Mount Everest at a height of 26 kilometres (12.4 miles).

3. CLOSEST TO HOME

Mount Tambora
Earth's most powerful eruption ever recorded was generated by this Indonesian volcano, peaking in April 1815.

DID YOU KNOW? Volcanic plumes rise up to 300km (190mi) above the surface of Io

Volcanoes on Io

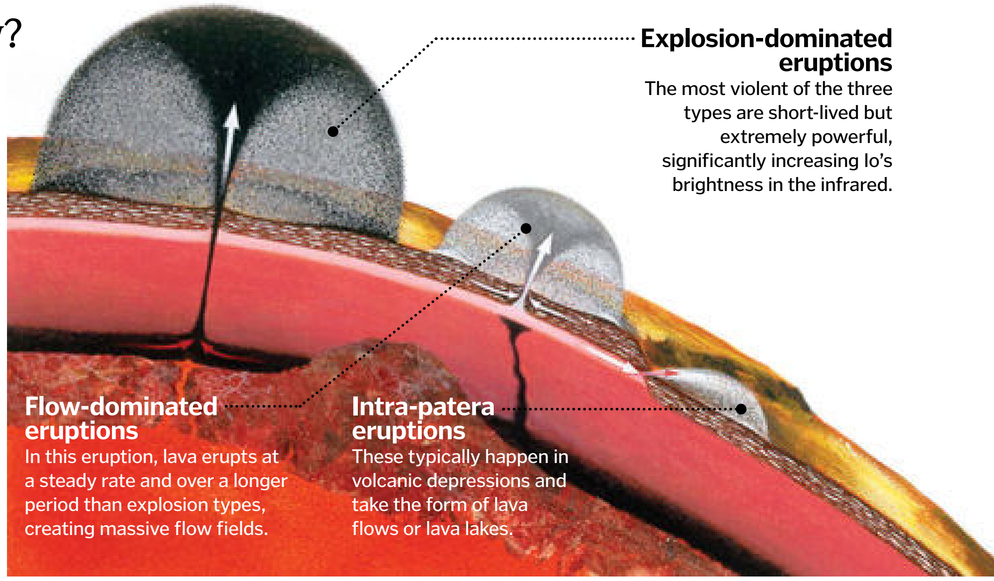
The Jovian moon's volcanic activity is different from ours on Earth – but how?

In 1979, the NASA probe Voyager 1 passed the innermost of the Galilean moons, Io, and spotted something remarkable: hot lava volcanoes. It's the only body in the Solar System other than our own world to have these fiery features and, in terms of volcanism, it makes Earth look lazy. As the Solar System's most volcanically active body, Io is host to over 400 active volcanoes spewing 100 times more lava each year than all the volcanoes on Earth. These are more or less evenly spread across Io's surface, supplied with lava from an ocean of magma 30-50 kilometres (20-30 miles) beneath its crust.

Unlike Earth, whose volcanism results from massive internal pressure, Io's geological activity comes from the influence of Jupiter's enormous gravity, which squeezes and stretches the moon in its eccentric orbit, generating friction and heat, keeping the rock inside Io molten.

Io-nic eruptions

We take a quick look at the three kinds of volcano observed on Io



Explosion-dominated eruptions
The most violent of the three types are short-lived but extremely powerful, significantly increasing Io's brightness in the infrared.

Flow-dominated eruptions
In this eruption, lava erupts at a steady rate and over a longer period than explosion types, creating massive flow fields.

Intra-patera eruptions
These typically happen in volcanic depressions and take the form of lava flows or lava lakes.

Why do astronauts train underwater?

A closer look at one of the many training exercises astronauts may undergo before venturing into space

One of NASA's many projects running concurrently to its space missions is NEEMO. It stands for NASA Extreme Environment Mission Operations and it prepares a crew for the conditions of space by putting them through 'analog' test missions: in other words, terrestrial missions which are analogous, or comparable, to those they will encounter on leaving this world.

An analog mission might require an astronaut to sit in a giant centrifuge and be spun at dizzying g-forces and various pressures in a specialised chamber or, in the case of NEEMO, it might focus on underwater activities that simulate low gravity.

NASA uses the Aquarius Reef Base situated off Key Largo in the Florida Keys for its NEEMO missions, which is owned by another US government department – NOAA (National Oceanic and Atmospheric Administration).

The base is a habitat located 19 metres (62 feet) underwater that weighs around 85 tons. The astronauts-in-training can stay in the habitat for several weeks, with training simulations like moving from one workstation to the next, using tools and working in an asteroid space environment.

NEEMO crew members (known as aquanauts) get to experience similar conditions to those they'd encounter in outer space

DID YOU KNOW? *White Sands was also used to conduct the Trinity test in 1945 – the first detonation of a nuclear device*

The Orion Launch Abort System

How does the LAS save a rocket's crew if things go wrong?

Launching a new spacecraft is an extremely tense time for NASA, especially when it carries the lives of several astronauts on board. Despite rigorous testing beforehand, the unpredictable can and has happened in the past, so the space agency has been trialling its latest contingency for a worst-case scenario, in which the crew need to be brought safely back down to Earth.

Developed originally for the Orion spacecraft as part of the cancelled Constellation programme (and now a vehicle designed for escaping the ISS in an emergency), the Launch Abort System (LAS) has since been tested by the Orion Pad Abort 1 team at the White Sands Missile Range, New Mexico. The test propelled a dummy crew module at 716 kilometres (445 miles) per hour to around two kilometres (1.2 miles) high, with a motor providing 227,000 kilograms-force (500,000 pounds-force) of initial thrust to get it off the ground. It is kept on course by an attitude control motor (ACM) with eight thrusters, with a combined 3,175 kilograms-force (7,000 pounds-force) of thrust.

The jettison motor kicks in when the abort motor burns out: explosive bolts fire and the jettison engine separates the LAS from the crew module. Once the module is clear, its recovery parachutes deploy and then it drifts gently back to the ground.

This 2010 test was the first US-designed abort system since Apollo and it was a total success. The data gathered during the Orion LAS test can be used for refining the design of future abort systems, providing ever better ways for the crew to escape a launch emergency.

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“New Horizons achieved the fastest escape velocity ever at 57,600 kilometres [35,800 miles] per hour”

What is NASA’s New Horizons?

Why has NASA sent a spacecraft all the way to Pluto and what does it expect to find there?

Pluto has long been a source of fascination for science – partly because, at a minimum of 4.4 billion kilometres (2.7 billion miles) at its closest orbital approach to the Sun, it has been beyond the effective reach of all but one spacecraft: Voyager 1. NASA instead opted for a close flyby of Titan (Saturn’s biggest moon), which put it beyond a compatible trajectory for Pluto.

That’s one reason why, in 2006, NASA sent the New Horizons spacecraft off to Pluto tasked with a double-reconnaissance of the dwarf planet and its largest satellite, Charon, as well as an extended mission into the most distant parts of the Solar System to investigate objects in the mysterious Kuiper Belt. At the time of writing, New Horizons has taken its payload of scientific instruments 25 astronomical units (which is approximately 3.7 billion kilometres/2.3 billion miles) and is scheduled to begin its Pluto flyby in July 2015.

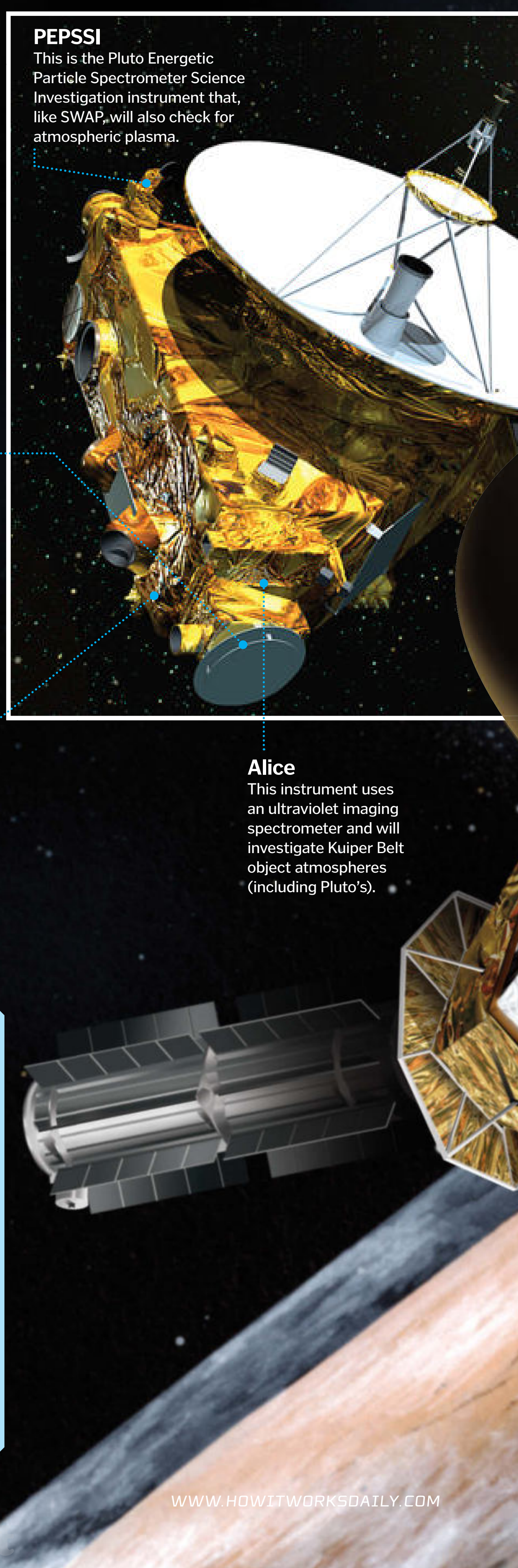
Piggybacking an Atlas V rocket (the same kind used for NASA’s Mars Reconnaissance Orbiter and Mars Science Laboratory) for launch, New Horizons achieved the fastest escape velocity ever at 57,600 kilometres (35,800 miles) per hour, on a trajectory that should see it reach Pluto around July 2015.

New Horizons won’t be landing anywhere or launching a vehicle (like the MSL and Curiosity, for example), so its seven main instruments are primarily designed to scan designated items of interest and answer questions like what Pluto’s gradually depleting atmosphere is comprised of, what the surface of both Pluto and Charon look like and generally what else can be found in the uncharted Kuiper Belt.

Among them, an instrument called ‘Ralph’ will take care of map-making, ‘Alice’ will provide atmospheric data via an ultraviolet spectrometer and REX is primarily responsible for making sure all the data collected is transmitted safely across the five light hours it takes to reach Earth from Pluto.

What’s on board?

A closer look at the scientific instruments aboard New Horizons and what they do



Deep-space dangers

In the seven years that New Horizons has spent on its journey to Pluto, scientists have discovered potential new hazards to the spacecraft. When New Horizons set off, only three of Pluto’s five satellites were known about: Charon had been discovered in 1978, Nix and Hydra both in 2005. Since then, the Hubble telescope has spotted two more, known simply as P4 and P5. The prospect of finding additional satellites before New Horizons arrives makes calculating a safe orbit of Pluto more complicated in itself, but these new moons are known as ‘debris generators’, filling Pluto’s orbit with material they have drawn in from the Kuiper Belt. A particle the size of a sand grain can potentially destroy this spacecraft travelling at such a high velocity. To deal with this, NASA is making multiple contingencies to avoid these debris zones as well as plotting a ‘bail-out trajectory’ to take New Horizons to safety.

THE STATS
PLUTO TRIVIA

PLUTO'S ORBITAL PERIOD **248 yrs**

TRAVEL TIME TO PLUTO **9.5 yrs**

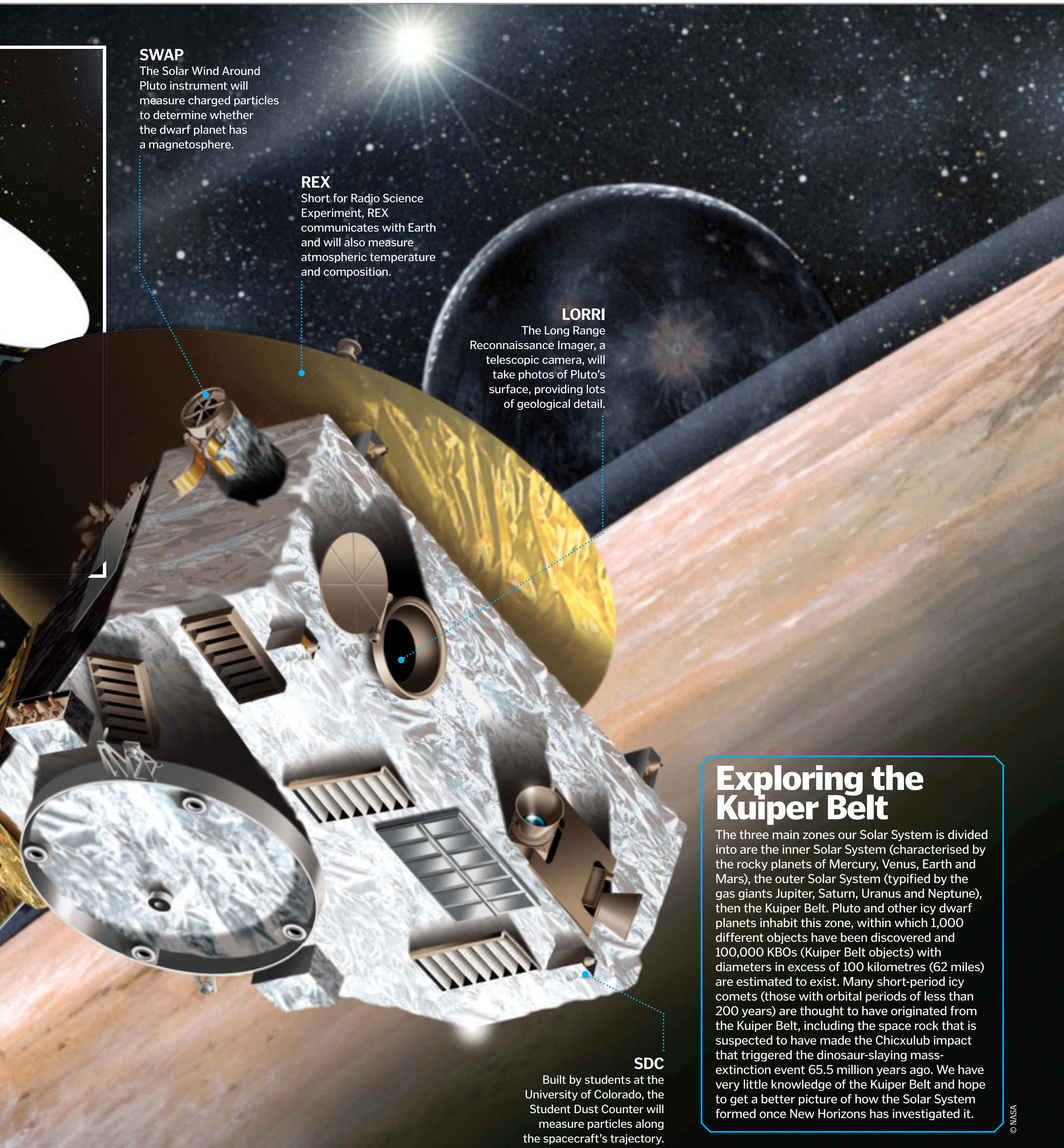
MEAN LIGHT HOURS TO PLUTO **5.36**

DIAMETER OF CHARON **1,270km**

ASTRONOMICAL UNITS TO THE KUIPER BELT **30**

YEAR PLUTO DISCOVERED **1930**

DID YOU KNOW? *New Horizons will cross the orbit of Neptune on 25 August 2014 – 25 years after Voyager 2 crossed it*



Exploring the Kuiper Belt

The three main zones our Solar System is divided into are the inner Solar System (characterised by the rocky planets of Mercury, Venus, Earth and Mars), the outer Solar System (typified by the gas giants Jupiter, Saturn, Uranus and Neptune), then the Kuiper Belt. Pluto and other icy dwarf planets inhabit this zone, within which 1,000 different objects have been discovered and 100,000 KBOs (Kuiper Belt objects) with diameters in excess of 100 kilometres (62 miles) are estimated to exist. Many short-period icy comets (those with orbital periods of less than 200 years) are thought to have originated from the Kuiper Belt, including the space rock that is suspected to have made the Chicxulub impact that triggered the dinosaur-slaying mass-extinction event 65.5 million years ago. We have very little knowledge of the Kuiper Belt and hope to get a better picture of how the Solar System formed once New Horizons has investigated it.

© NASA

The statistics...

Tyrannosaurus rex

Clade: Theropoda
Genus: Tyrannosaurus
Period: Late Cretaceous
Diet: Carnivore
Length: 12-13m (40-43ft)
Height: 4m (13ft)
Weight: 6-9 tons
Max speed: 40km/h (25mph)

Tyrannosaurus rex

Learn about the lizard king's physiology and how it presided over the prehistoric jungle

Tyrannosaurus rex was a species of Theropoda dinosaur in the Late Cretaceous period. Like other tyrannosaurids – such as Tarbosaurus and Gorgosaurus – the T-rex was a bipedal carnivore and apex predator and scavenger, preying on smaller dinosaurs directly or out-muscling them for their kills. Typical prey included hadrosaurs and ceratopsians.

Tyrannosaurus rex's name translates as 'tyrant lizard king' – something that was historically attributed due to its immense size. Indeed, the Tyrannosaurus rex is one of the largest species ever excavated by palaeontologists, with specimens averaging over 12 metres (40 feet) in length and four metres (13 feet) in height, but it wasn't the biggest carnivorous dino. It was also incredibly heavy with fully grown adults weighing up to nine tons; this figure was suggested in 2011 after an in-depth study which made digital 3D models of five T-rex skeletons.

Due to their considerable size, the Tyrannosaurus rex had very few, if any, predators – a fact that enabled it to remain unchallenged as the Late Cretaceous era's apex predator on land and to live for lengthy periods. Estimates taken from excavated specimens – of which there are now more than 30 confirmed around the world – indicate that the T-rex's life span was roughly 30 years, with the majority of growth taking place in the first 16 years before tailing off rapidly. This suggests that the Tyrannosaurus rex would have reached adulthood at approximately 20 years of age.

As with almost all species of Dinosauria, the Tyrannosaurus was wiped out 65.5 million years ago in the Cretaceous-Palaeogene (K-Pg) extinction event. At the time it was one of the last widespread non-avian dinosaurs, as evidenced by the discovery of many specimens throughout North America.

5 TOP FACTS
T-REX TRIVIA

Scavenger
1 Excavated evidence suggests that, as well as being an active predator, the Tyrannosaurus was also an opportunistic scavenger, commandeering kills from smaller carnivores.

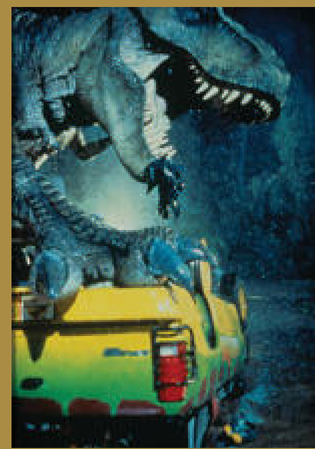
Cannibal
2 A study put forward in 2010 posits that Tyrannosaurus was cannibalistic. The theory was determined when researchers found specimens with same-genus tooth marks.

Bad posture
3 Tyrannosaurus rex was historically depicted with its body at 45 degrees or less from the vertical. This is not accurate, with a more horizontal posture likely.

Big foot
4 Two excavated fossilised footprints have been attributed to T-rex. The latest measures 83 centimetres (33 inches) in length and 71 centimetres (28 inches) wide.

Feathery young
5 According to a recent report in the journal *Nature*, Tyrannosaurus young may have been feathered for insulation, only losing their plumage in later years.

DID YOU KNOW? Tyrannosaurus rex was totally wiped out in the Cretaceous-Palaeogene extinction event



T-rex mythbuster

Due to a variety of films depicting the T-rex in their own unique way, an accurate view of the species has been clouded. For example, despite being a prominent star of all the *Jurassic Park* films, Tyrannosaurus rex did not exist in the Jurassic period (199-145 MYA). In fact, it lived millions of years later during the Late Cretaceous (100-65.5 MYA). Further, for decades T-rex has been depicted as having green scaly skin. However, recent evidence suggests its skin colour was varied and, during the early years of its life, it probably sported insulative feathers. The T-rex has also been commonly lauded as the biggest carnivorous dinosaur of them all. This isn't strictly true, with palaeontological evidence suggesting the species Spinosaurus outsized it by over three metres (9.9 feet) in length. And finally, another myth perpetuated in *Jurassic Park* is that the Tyrannosaurus could run at high speed (ie keep up with a car), but it could probably only manage about 40 kilometres (25 miles) per hour due to its relatively small strides.

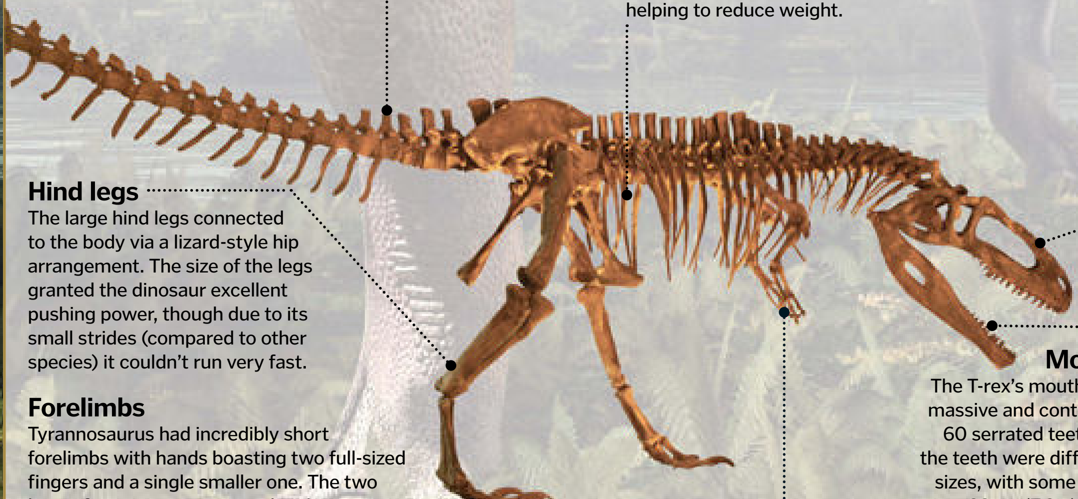
Anatomy of the lizard king

HIW analyses a Tyrannosaurus rex's skeleton to see what made it such a deadly predator

Tail
Crucial for maintaining balance – especially as modern evidence suggests T-rex had a near-horizontal spinal position – the dinosaur's large tail was essential for chasing prey.

Body cavity
The Tyrannosaurus rex had an incredibly heavy body structure and a wide body cavity. To improve mobility, some of the dinosaur's vertebrae had holes – helping to reduce weight.

Skull
Tyrannosaurus's skull was huge and its snout and lower jaw were very deep. The eye sockets faced forward to a greater degree than most dinosaurs, indicating it had acute binocular vision.



Hind legs
The large hind legs connected to the body via a lizard-style hip arrangement. The size of the legs granted the dinosaur excellent pushing power, though due to its small strides (compared to other species) it couldn't run very fast.

Forelimbs
Tyrannosaurus had incredibly short forelimbs with hands boasting two full-sized fingers and a single smaller one. The two larger fingers were equipped with razor-sharp, sickle-shaped claws.

Mouth
The T-rex's mouth was massive and contained 60 serrated teeth. All the teeth were different sizes, with some up to 20cm (7.9in) long.

"It wasn't uncommon to encounter books bound in human skin"

How were books bound?

When did people first start to make books and what exactly did the process involve?

When a collection of written pages were bound together to form a codex – the earliest form of a book – the craft of bookbinding was invented. By this definition, one of the oldest known books in the world is a 2,500-year-old, six-page volume written in Etruscan (the now-dead language of a pre-Roman Italian civilisation).

With the rise in demand for the Christian Bible, the creation of large books began to gain popularity. From the 5th century up until the Middle Ages, books were often bound using a vellum (finely scraped animal hide) writing surface with flat spines and wooden covers, secured with clasps to stop humidity from warping its shape.

The vellum was placed together in several folded sheets to form a group of up to eight pages called an octavo section. As a section, these pages would be more resilient to tearing when sewn together. They were then sandwiched between wooden panels and covered with the material of the bookbinder's choice: cloth, leather or even gemstones and ivory for more wealthy clients. More gorily, during the Dark Ages and early medieval times, it wasn't uncommon to encounter books that were bound in human skin!

A traditional bookbinder applies the binding to the spine of a book

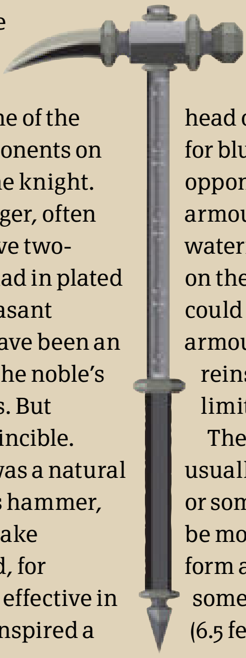
Medieval warhammers

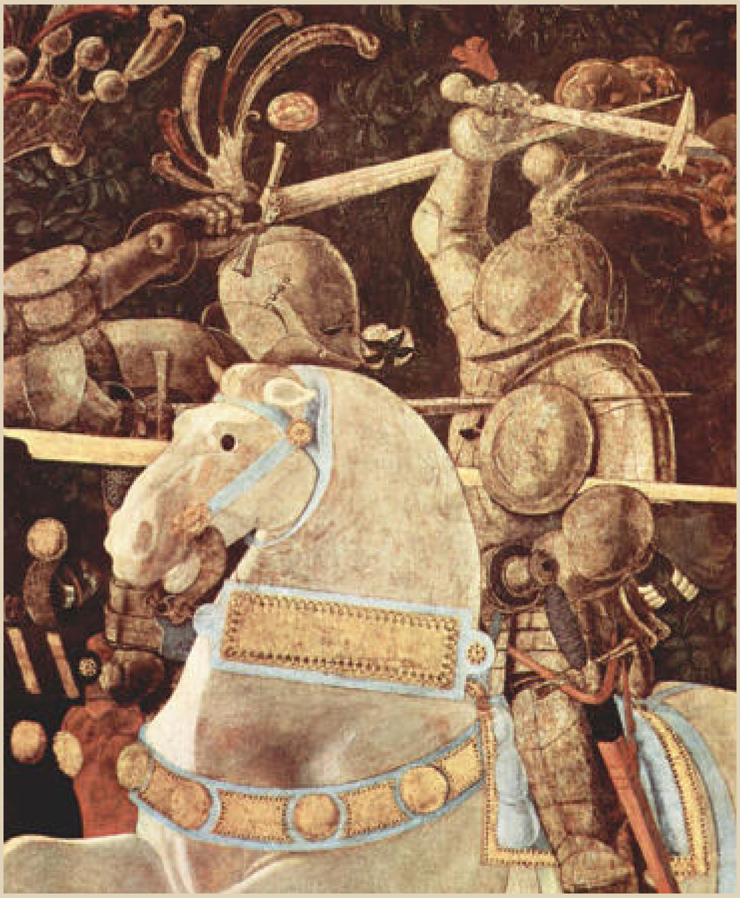
Discover how these terrifying weapons were made and used on the battlefield

In the melee arms race that was medieval warfare, one of the most formidable opponents on the battlefield was the knight. Sitting astride a charger, often wielding an expensive two-handed sword and clad in plated mail, to the lowly peasant infantry they must have been an imposing display of the noble's prestige and prowess. But knights were not invincible.

The warhammer was a natural evolution of a smith's hammer, relatively cheap to make (compared to a sword, for example) and was so effective in its versatility that it inspired a range of adaptations. The traditional warhammer had a blunt head on one side that was used for bludgeoning unarmoured opponents and stunning armoured knights. An eye-watering spike was mounted on the opposite side, which could pierce shields and armour or grapple with the reins and legs of a horse to limit manoeuvrability.

The hammerhead was usually made from heavy iron, or sometimes lead, and could be mounted onto a shaft to form a kind of pole-arm, sometimes up to two metres (6.5 feet) in length.



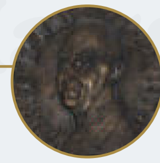


KEY DATES
CHICAGO PILE-1

1942 The first self-sustaining nuclear chain reaction is initiated in Chicago Pile-1 on 2 December.

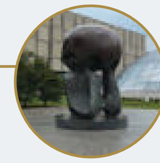
1943 Operation of Chicago Pile-1 ends in February with the reactor moved to Red Gate Woods.

1954 The key architect of the Chicago Pile-1, Italian physicist Enrico Fermi, passes away aged 53.



1965 The site of Chicago Pile-1 is designated as a National Historic Landmark on 18 February.

1967 Henry Moore creates a bronze sculpture called *Nuclear Energy* for the University of Chicago.



DID YOU KNOW? Chicago Pile-1 was built under a rackets court in the grounds of the University of Chicago

The world's first nuclear reactor

The success of Chicago Pile-1 heralded the dawn of a new age of nuclear power around the world

No camera was taken to the event, but this illustrates the critical moment on 2 December 1942

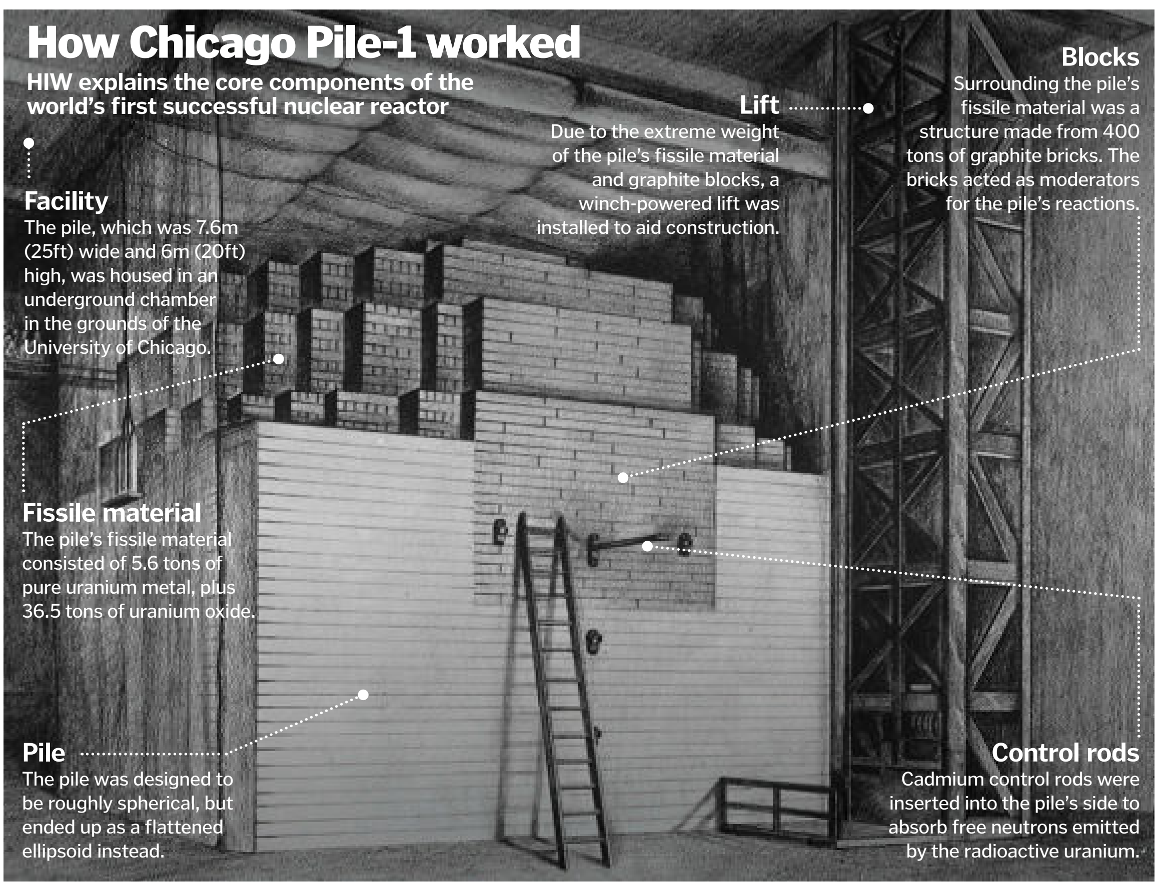
Chicago Pile-1 was the first nuclear reactor in the world to achieve a stable, self-sustaining nuclear chain reaction. It achieved this feat on 2 December 1942 and would lead to the development of nuclear power as a viable source of energy.

The reactor was constructed underneath a rackets court at the University of Chicago as part of the wider Manhattan Project (see 'The pile's pioneer' boxout for more information) and consisted of a large pile of uranium and graphite blocks assembled in a flattened ellipsoid shape.

The completed pile contained over 349,720 kilograms (771,000 pounds) of graphite, 36,555 kilograms (80,590 pounds) of uranium oxide and 5,625 kilograms (12,400 pounds) of uranium metal. Control of the pile's reactions was achieved with a series of cadmium rods, which were inserted from the outside and absorbed neutrons. As such, withdrawing the rods would increase neutron activity, while inserting more would decrease it.

On 2 December 1942 the reactor went critical at 3.25pm, with lead scientist Enrico Fermi confirming the reactor was producing a self-sustaining reaction. The reactor remained operational for 28 minutes, producing 0.5 watts of energy (enough to power a small light bulb) before being shut down.

Following the success of Pile-1, it was deconstructed and moved to Red Gate Woods – the future site of the Argonne National Laboratory. More powerful reactors were built on the site and this research led to the invention of light and heavy water reactors, fast reactors and a large number of the designs that are used as the basis for today's commercial reactors.



Enrico Fermi received the 1938 Nobel Prize in Physics for his work on nuclear reactions and identification of new elements

The pile's pioneer

The Chicago Pile-1 was assembled under the supervision of famous Italian physicist Enrico Fermi. Fermi had been awarded the Nobel Prize in Physics four years previously for his work in induced radioactivity and began lecturing at Columbia University, NY.

In 1942 the laboratory group at Columbia, led by Fermi, was asked to move to the University of Chicago to work on the Manhattan Project (the research and development programme that would lead to the first atomic bomb) and it was from this work that the idea of constructing Chicago Pile-1 emerged.

The money to build the pile came from the US government itself, which on the back of a letter written by Albert Einstein and Leó Szilárd, warning that Nazi Germany was attempting to develop an atomic bomb, led to President Roosevelt contributing $6,000 to the research.

Fermi took control of both the design and build, as well as running every calculation with meticulous detail. This led to a series of successful trial runs and, eventually, the now famous events of 2 December 1942.

"The complex, which was largely built by king Suryavarman II, was in dedication to the Hindu god Vishnu"

The wonders of Angkor Wat

Part of an ancient Cambodian capital, Angkor Wat was the spiritual epicentre of the Khmer Empire

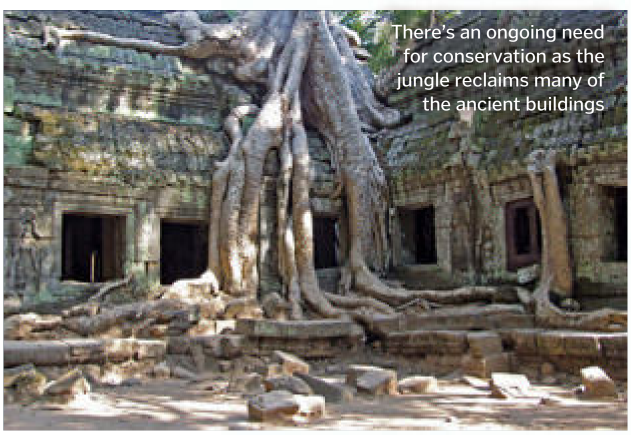
Angkor Wat is a temple complex in north-west Cambodia. Today it is an archaeological site, but from the early to mid-12th century Angkor was the capital city of the Khmer Empire – one of the most powerful civilisations in south-east Asia.

The complex, which was largely built by Khmer king Suryavarman II, was in dedication to the Hindu god Vishnu and, upon completion, covered an area of 820,000 square metres (8.8 million square feet), with numerous towers, temples, courtyards and dwellings encircled by a stone wall. The temple complex was accessed by an earth bank to the east and a sandstone causeway to the west – the latter being the main entrance for officials and royalty.

At the centre of the complex lay a quincunx of large ornate towers (positioned like the five dots on a die), which represented the spiritual Mount Meru – the home of the Hindu gods. The five towers symbolised the five peaks of the mountain, while the surrounding moat represented the ocean that was supposed to surround them. These central towers, as well as the inner temple, were only open to the royal family and high-ranking officials.

Surrounding the central temple was a large outer enclosure that originally would have housed the majority of the city's dwellings. These were built out of wood and other easily perishable materials and, as a result, no record of them survives today, with the majority of the outer enclosure now densely populated with jungle vegetation. To the north of the temple lay the royal palace, while a selection of grand stone libraries sat in the peripheries.

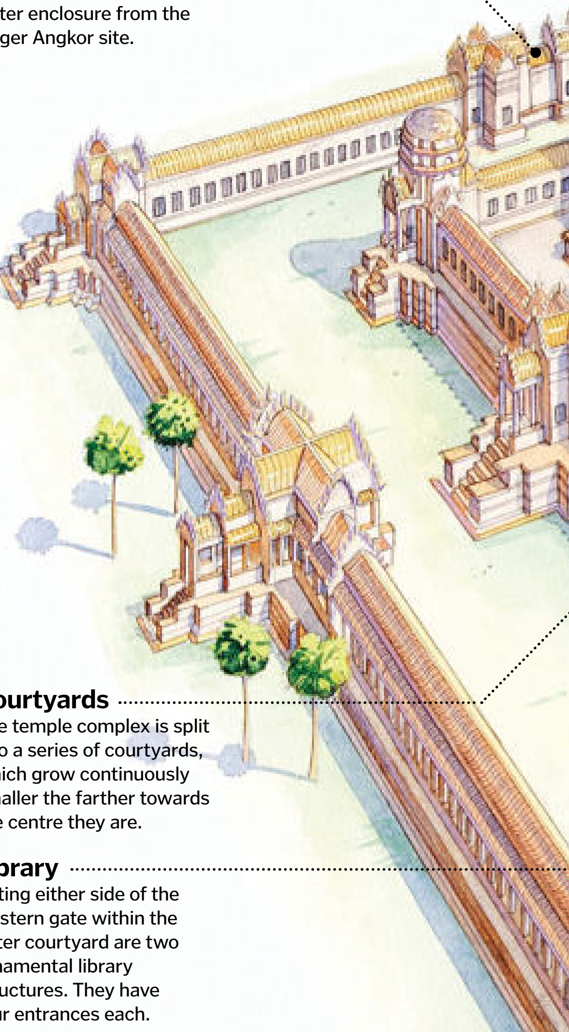
Today Angkor Wat is a central part of the Angkor Archaeological Park, a UNESCO World Heritage Site that encompasses 400 square kilometres (152 square miles) of temples, forest and hydraulic structures such as reservoirs and canals dating from the 9th to 15th century.



There's an ongoing need for conservation as the jungle reclaims many of the ancient buildings

Inside Angkor Wat

Take a look around one of the most important archaeological sites in south-east Asia



Eastern gate
To the east, a subsidiary gate is reached by an earthen bank, which crosses the moat separating the outer enclosure from the larger Angkor site.

Courtyards
The temple complex is split into a series of courtyards, which grow continuously smaller the farther towards the centre they are.

Library
Sitting either side of the western gate within the outer courtyard are two ornamental library structures. They have four entrances each.

The statistics...

Angkor Wat

Built: 12th century

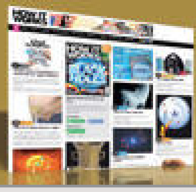
Country: Cambodia

Location: Angkor, Siem Reap Province

Area: 820,000m² (8.8 million ft²)

Style: Khmer, Dravidian

Architect: Suryavarman II

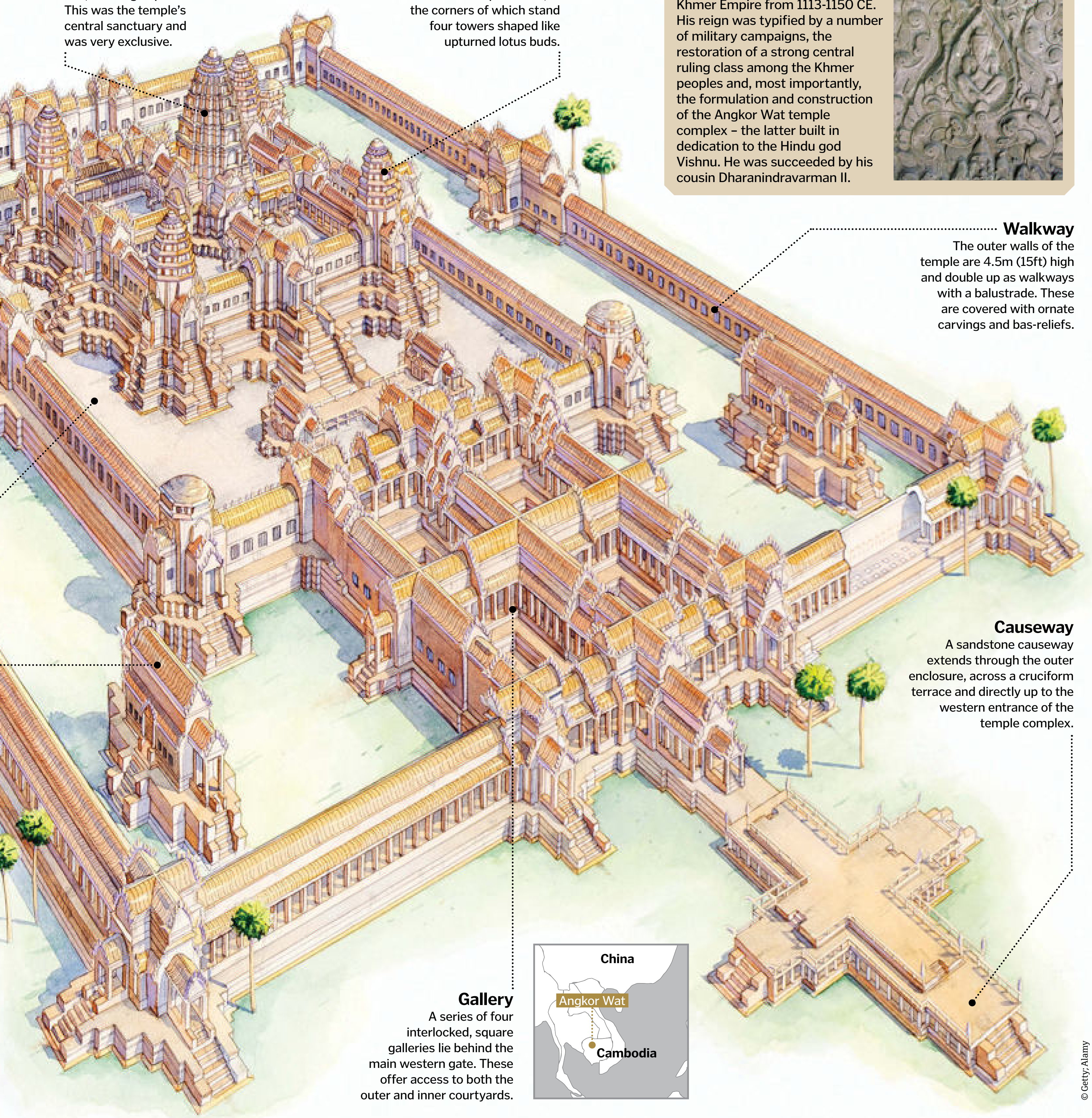


AMAZING VIDEO!
SCAN THE QR CODE FOR A QUICK LINK

Learn how Angkor Wat was constructed now

www.howitworksdaily.com

DID YOU KNOW? *The entire Angkor Wat temple complex was completed in just 40 years*



Sanctuary
At the centre of the four other towers sits a larger one, creating a quincunx. This was the temple's central sanctuary and was very exclusive.

Tower
Angkor Wat rises towards the centre on a series of colonnaded platforms, in the corners of which stand four towers shaped like upturned lotus buds.

Who was Suryavarman II?

Suryavarman II was the king of the Khmer Empire from 1113-1150 CE. His reign was typified by a number of military campaigns, the restoration of a strong central ruling class among the Khmer peoples and, most importantly, the formulation and construction of the Angkor Wat temple complex – the latter built in dedication to the Hindu god Vishnu. He was succeeded by his cousin Dharanindravarman II.

Walkway
The outer walls of the temple are 4.5m (15ft) high and double up as walkways with a balustrade. These are covered with ornate carvings and bas-reliefs.

Causeway
A sandstone causeway extends through the outer enclosure, across a cruciform terrace and directly up to the western entrance of the temple complex.

Gallery
A series of four interlocked, square galleries lie behind the main western gate. These offer access to both the outer and inner courtyards.

Ask your questions

Send us your queries using one of the methods opposite and we'll get them answered

BRAIN DUMP

Because enquiring minds want to know...

MEET THE EXPERTS

Who's answering your questions this month?

Luis Villazon

Luis has a degree in Zoology from Oxford University and another in Real-time Computing. He's been writing about science and tech since before the web. His science-fiction novel *A Jar Of Wasps* is published by Anarchy Books.

Giles Sparrow

Giles studied Astronomy at UCL and Science Communication at Imperial College, before embarking on a career in publishing. His latest book, published by Quercus, is *The Universe: In 100 Key Discoveries*.

Alexandra Cheung

With degrees from the University of Nottingham and Imperial College, Alex has worked for several scientific organisations including London's Science Museum, CERN and the Institute of Physics. She lives in Ho Chi Minh City, Vietnam.

Michael Simpson

Michael has a doctorate in moss and teaching awards from the University of Alberta. While not working as an expat botanist and environmental consultant, he writes for magazines and websites on TV programmes, technology and science.

Aneel Bhangu

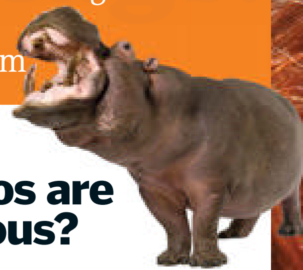
Aneel is a training academic surgeon working in London. His main research interests include advanced cancers and medical statistics, with his clinical interests including planned surgery for rectal cancers and emergency surgery for trauma.

Why do we use liquid hydrogen propellant?

Harry Anderson

Liquid hydrogen is used as a rocket propellant because it has the highest efficiency relative to the amount used, over any other known propellant. In combination with an oxidiser like liquid oxygen, it's light and extremely powerful, burning at over 3,000 degrees Celsius (5,500 degrees Fahrenheit). There were, however, significant challenges and hazards to using liquid hydrogen when it was being developed in the Sixties. Both liquid hydrogen and liquid oxygen are cryogenic gases, meaning they only phase-change to liquid at an extremely low temperature. Liquid hydrogen needs to be stored at -252 degrees Celsius (-423 degrees Fahrenheit) and carefully insulated from all sources of heat to prevent it from boiling off and to stop it expanding and exploding the propellant tank. Liquid hydrogen can also seep through tiny cracks between welds in the tank, so some very technical engineering must be employed to create a rocket capable of safely using this kind of propellant. **HIW**

Inset: The upper stage of the very first liquid hydrogen rocket, the Centaur, was developed by NASA and successfully launched in 1963



Is it true that hippos are incredibly dangerous?

Kurt Freesman

■ As they wallow in the waters of a muddy river, hippos look like the layabouts of the African savannah. Yet this suggestion of lethargy disguises their potential for terrifying ferocity. Hippos are territorial animals in water and not afraid to intimidate rivals and predators invading their space. They are also known to attack humans that get too close. A hippo's ivory tusks – actually extended canine teeth – make for formidable weapons. Together with a wide gape and powerful jaw muscles, they give the hippopotamus a killer bite. Swimming hippos are particularly dangerous because their buoyancy allows them to move their bulk with surprising speed. An adult could easily capsize a canoe.
Michael Simpson

Hippos can spend up to 16 hours a day in water and are surprisingly good swimmers

How do engineers demolish a skyscraper?

Steven Seymore

■ First, the building is stripped as much as possible, removing copper wire and aluminium for recycling, as well as all the windows and insulation to prevent health-and-safety hazards from flying debris. Then explosives are used to shatter the load-bearing structures on some of the floors. The explosives are synchronised using detonating cord – a thin plastic pipe filled with an explosive called pentaerythritol tetranitrate (PETN), which burns at 6.4 kilometres (four miles) per second. The aim is for the upper storeys to fall vertically down, so that the whole building collapses onto its own footprint and surrounding buildings aren't damaged.

In France, the technique of vérinage is often used instead of explosives. This employs hydraulic rams to push the load-bearing members of one of the middle floors sideways. At a certain point they all give way at the same time and the top half of the building falls straight down onto the bottom half. The end result is very similar to an explosive demolition.

Meanwhile the Japanese Kajima Construction Corporation has developed a system of propping up an entire tower block with hydraulic jacks and demolishing the ground floor using ordinary diggers and bulldozers. The jacks then lower the building down a storey and the process repeats.
Luis Villazon

What are freckles and how are they caused?

Natalie

■ Freckles are clusters of the pigment melanin. It is produced by melanocytes deep in the skin, with greater concentrations giving rise to darker skin tones, and hence, ethnicity. Melanin protects the skin against harmful ultraviolet sunlight, but is also found in other locations around the body, such as the brain. Freckles are mostly genetically inherited, but not always. They become more prominent during sunlight exposure, as the melanocytes are triggered to increase production of melanin, leading to a darker complexion. People with freckles generally have pale skin tones, and if they stay in the Sun for too long they can damage their skin cells, leading to skin cancers like melanoma.
Aneel Bhangu

The only reason the hammer falls faster here on Earth is air resistance, not mass

Does a heavier object fall quicker?

Pamela Smith

■ Surprising as it might seem, an object's mass has no impact on how fast it falls. Instead, its speed is determined by a property of gravity called gravitational acceleration (or g for short), which is 9.81 metres per square second at the surface of our planet. This means that in one second, any object's downward speed will increase by 9.81 metres (32.2 feet) per second because of gravity, regardless of mass. Having said that, if you imagine dropping a feather and a hammer at the same time, you don't need to be a physicist to guess that the hammer will fall faster (mind your toes!). Gravity accelerates both objects at the same rate, but another factor comes into play: air resistance. The feather is slowed down more by the air and floats down gently, while the hammer crashes straight to the ground.

Apollo 15 astronauts tried out this exact experiment on the Moon where there is no air, and consequently no air resistance – both hammer and feather landed at the same time. Back here on Earth, if you dropped two objects with exactly the same shape and volume but different mass, they would also fall at the same speed.
Alexandra Cheung

Could anyone become a knight? Find out on page 84

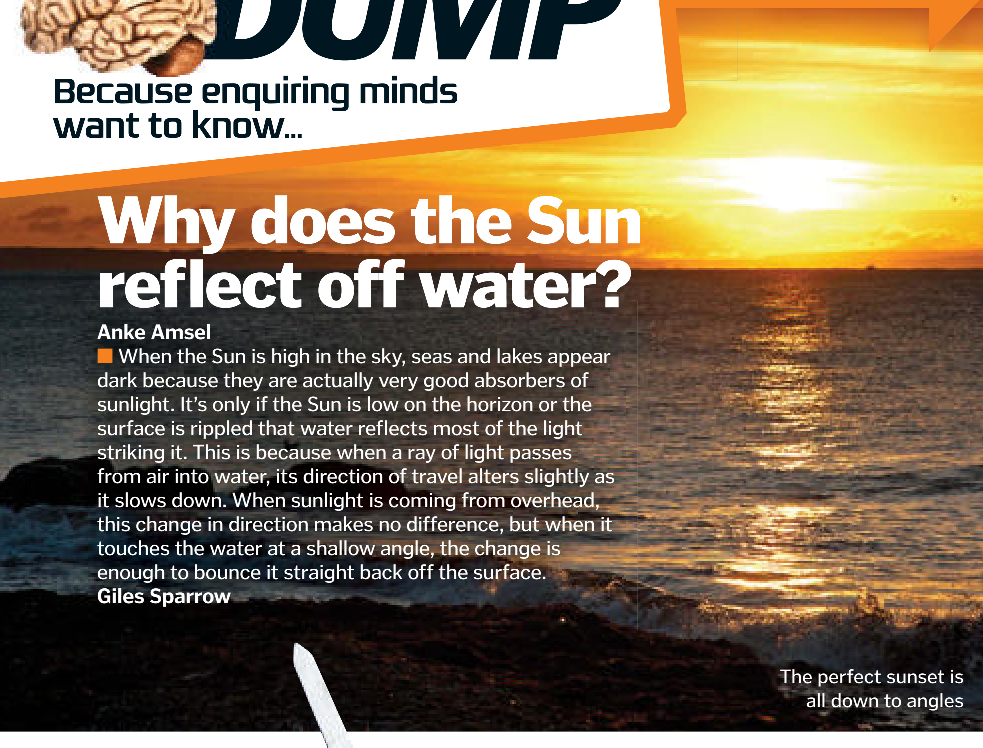
BRAIN DUMP

Because enquiring minds want to know...

Why are ash trees dying?
Find out on page 85

Want answers?

Send us your questions using one of the methods opposite and we'll get them answered



Why does the Sun reflect off water?

Anke Amsel

■ When the Sun is high in the sky, seas and lakes appear dark because they are actually very good absorbers of sunlight. It's only if the Sun is low on the horizon or the surface is rippled that water reflects most of the light striking it. This is because when a ray of light passes from air into water, its direction of travel alters slightly as it slows down. When sunlight is coming from overhead, this change in direction makes no difference, but when it touches the water at a shallow angle, the change is enough to bounce it straight back off the surface.
Giles Sparrow

The perfect sunset is all down to angles

Sam Heath set the record for most people inside a bubble in 2006, with 19 children fitting inside!

Could anyone become a knight in medieval times?

Adam Frank

■ In general, any medieval soldier could be considered for knighthood after showing exceptional bravery in battle. The sons of nobles had a foot in the door, though, by virtue of their status and connections. At around the age of eight these children were packed off to a castle to be a page. A page would run errands for a lord or knight, receive basic combat training and get beefed up enough to wear armour and wield a heavy sword. In the classroom a page would be introduced to chivalry and learn how to read, write and speak in French and Latin. In their mid-teens those who had impressed would be promoted to knight's squire. Duties could include dressing and waiting on their employer as well as maintaining the knight's gear and being his shield carrier. Also a squire's physical training was more intense because he might have to go into battle alongside his master. If the squire fought well, he could arise to knighthood at around the age of 20. He could then lead his own squires into battle hoping that all his noble training wouldn't go to waste at the end of an enemy sword.
Michael Simpson

What causes people to have straight or curly hair?

Levi Briggs

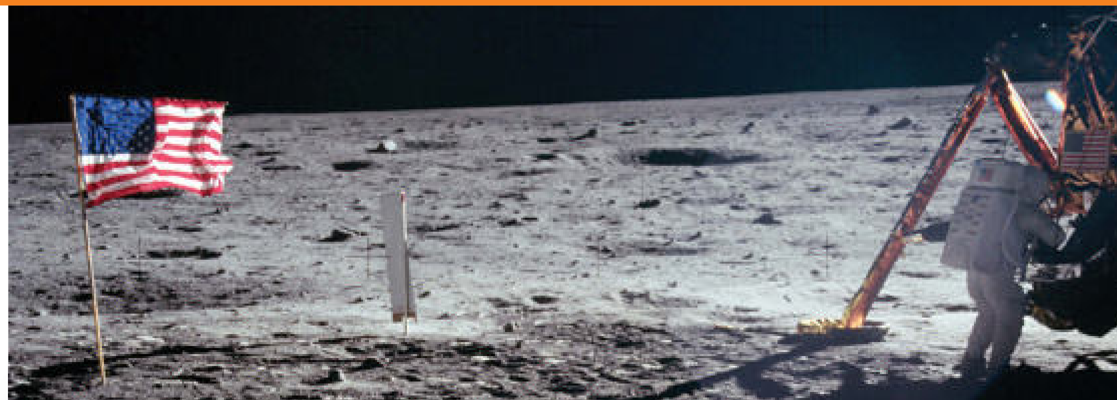
■ This is entirely down to your parents – or more specifically, the genes you inherited from your parents. Curly hair is an autosomal dominant trait. That means if one of your parents gives you a curly-haired gene but the other gives you a straight-haired gene, the 'stronger' curly-haired gene wins the day and expresses its trait. However, it's not always quite so clear cut, and depending on the type and strength of the genes, you can end up with something in between, such as wavy hair. Other examples of autosomal dominance include brown over blue eyes, freckles over no freckles, and dark over blonde hair.

With approximately 100,000 hairs on the human head, it's a busy area of growth. Hair starts growing in follicles that are located in the dermal layer of the skin. Flattened hair follicles lead to thinner hair strands that naturally curl. Rounder hair follicles lead to tubular strands of hair that are harder to curl, and so grow straight. Of course, some people with straight hair want curly hair, and vice versa. Straightening or curling hair is a way to overcome genetics, but it won't last very long as the hair will continue to grow in its natural way.
Aneel Bhangu

Why are huge bubbles wobbly, but tiny ones perfect spheres?

Elizabeth Armstrong

A bubble's shape is essentially a tradeoff between the forces acting on it. Surface tension and external pressure squeeze inwards, shrinking the bubble's surface area, while the air trapped inside pushes back. The bubble therefore adopts a shape that has the smallest surface area for a given volume: a sphere. Changes in external pressure – like a gust of wind – disrupt this equilibrium and the bubble 'wobbles' as it adjusts to maintain the balance of forces. For a small bubble, surface tension is relatively strong, and thus it can regain its shape quickly. However, surface tension doesn't grow stronger as a bubble increases in size – quite the opposite, in fact. As a result, the bigger the bubble, the more influential external pressure becomes and the more vulnerable it is to turbulence.
Alexandra Cheung



How long did Neil Armstrong's first moonwalk last?

Alice Cole

From the moment Neil Armstrong stepped out the Eagle Lunar Module, the Apollo 11 moonwalk lasted two hours and 36 minutes – not long considering the entire mission lasted more than eight days. The first thing he did after stepping onto the surface was to collect a sample of the soil in case they had to abandon the mission in a hurry. Armstrong and his crewmate Buzz Aldrin then set up a variety of equipment including a TV camera and a flag, plus a host of experiments including a moonquake detector and a reflector, which could be used to measure the Moon's precise distance. They also collected further soil samples and took some famous holiday snaps.
Giles Sparrow

Why are ash trees in the UK under threat?

Laurence Burn

Ash dieback disease is caused by the fungus Chalara fraxinea. The disease begins with the leaves wilting and turning black and then spreads. As the fungus grows into the tree it blocks the xylem vessels, which transport water in the trunk and branches, and the tree eventually dies. The disease has become entrenched across most of Europe, but it has only recently been confirmed in the UK. There are 80 million ash trees in Britain and over 100,000 seedlings/saplings have already been destroyed to try and control the disease. In Asia, ash trees are immune to the disease so it's possible a treatment might be derived from them.
Luis Villazon

How does electricity make a motor turn?

Billy Rooke

Electric motors use magnets to convert electricity into motion. Electrons have weak magnetic properties, but these usually cancel each other out. An electric current, however, forces unpaired electrons inside a metal wire to line up, allowing them to join forces and create a coherent magnetic field. This field is very weak, but by wrapping the wire into a coil its strength is multiplied – this is an electromagnet. Inside an electric motor, permanent magnets are set onto a ring surrounding a coil of wire. When the appliance's switch is flicked on, electrons flow through the wire, turning it into an electromagnet. The attractive and repulsive forces of the permanent magnets around it make the electromagnet spin. This circular motion is then used to power anything from a fan to an electric car.
Alexandra Cheung

What are 'bingo wings' and why don't men get them?

Andrea Walters

'Bingo wings' – also known as 'bat wings' – are collections of fatty cells underneath the arm, which can sag down and wobble and look a little like wings. As we age, the structural collagen in our bodies becomes increasingly weaker, leading to the sagging we see. They typically affect women more than men (though men can get them), due to two main factors. Firstly, women have a wide distribution of fat around the whole body, whereas for men fat is largely centred over the abdomen. Secondly, women undergo a series of hormonal changes which men don't, which can affect the size and structure of their fat cells.
Aneel Bhangu

Who created fortune cookies? Find out on page 86

BRAIN DUMP

Because enquiring minds want to know…

How do we make marbles?
Find out on page 87

Want answers?

Send us your questions using one of the methods opposite and we'll get them answered

How many nations are in the Caribbean and which is the biggest?

Penny Stanton

The answer to this question depends on how the term 'nation' is defined. Some Caribbean islands are independent countries, the largest being Cuba (110,860 square kilometres/42,803 square miles) and the smallest being Saint Kitts and Nevis (261 square kilometres/104 square miles). Other communities are answerable to another country, including Britain's Overseas Territories and Aruba, which is part of the Kingdom of the Netherlands. Also, several Latin and South American countries have Caribbean coastlines, including Venezuela and Mexico. The Association of Caribbean States includes some but not all places in these categories among its 28 Contracting States, Countries and Territories.
Michael Simpson

At around 620km^2 (239mi^2), Saint Lucia in the Windward Islands is one of the smallest Caribbean isles

Where did fortune cookies originate?

David Crofton

The majority of food historians suspect that the modern form of this prophesying confection originated not in China but in one of two American cities. Around the start of the 20th century Makoto Hagiwara, a Japanese-American caretaker of Golden Gate Park's Japanese Tea Garden in San Francisco, reputedly gave out notes of gratitude embedded in cookies after a sympathetic mayor gave him his job back. His inspiration might have been similarly folded cookies that have been made in bakeries in Japan for generations. Around 20 years later in Los Angeles, Chinese immigrant David Jung – founder of the Hong Kong Noodle Company – supposedly handed out cookies containing inspiring messages to the city's poor. Yet exactly how either of their creations later became associated with westernised Chinese cuisine isn't clear.
Michael Simpson

Is it true that if you wear a coat inside, you won't feel its benefit when you go outside?

Helen Jackson

The answer is found in a combination of biology and survival tactics. Hypothermia sets in when the core body temperature drops by one or two degrees Celsius. Waiting until you're outside before putting your coat on will lead to a short but significant loss of body heat through convection and conduction until you cover up. Leaving your coat on all the time indoors will lead to vasodilatation, which can also increase your heat loss and take time to reverse when you step outside. The answer may be a compromise: putting your coat on shortly before you're due to go outside will allow a warm, protective layer of heated air to be captured around your body without causing excessive vasodilatation.
Aneel Bhangu

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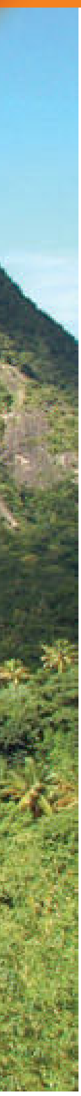
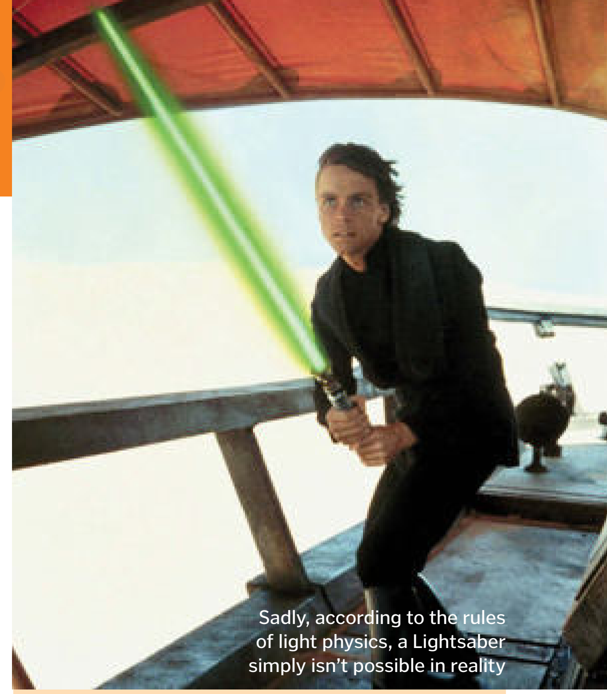


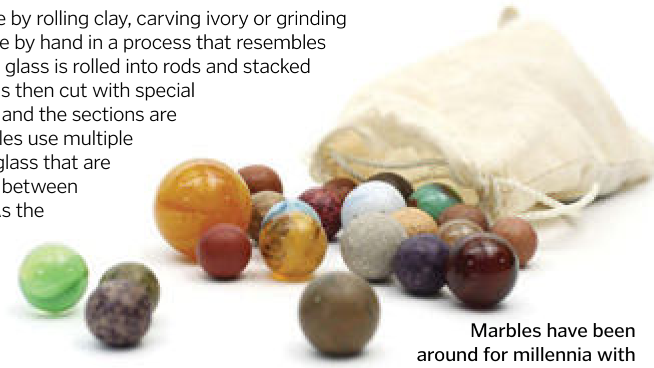


Sadly, according to the rules of light physics, a Lightsaber simply isn't possible in reality

How are marbles made?

Jenny Joyce

The oldest marbles were handmade by rolling clay, carving ivory or grinding stone. Glass marbles can also be made by hand in a process that resembles making seaside rock. Molten coloured glass is rolled into rods and stacked together to form a pattern. The glass is then cut with special scissors, while it is still soft like toffee and the sections are rolled into balls. Mass-produced marbles use multiple nozzles to combine streams of liquid glass that are cut into even-sized lumps and passed between two parallel, rotating screw threads. As the screws rotate, the marbles are moved along the production line, constantly rolling to form into perfect spheres as they cool. Fancier marbles are sometimes coated with powdered glass of other colours as they roll.
Luis Villazon



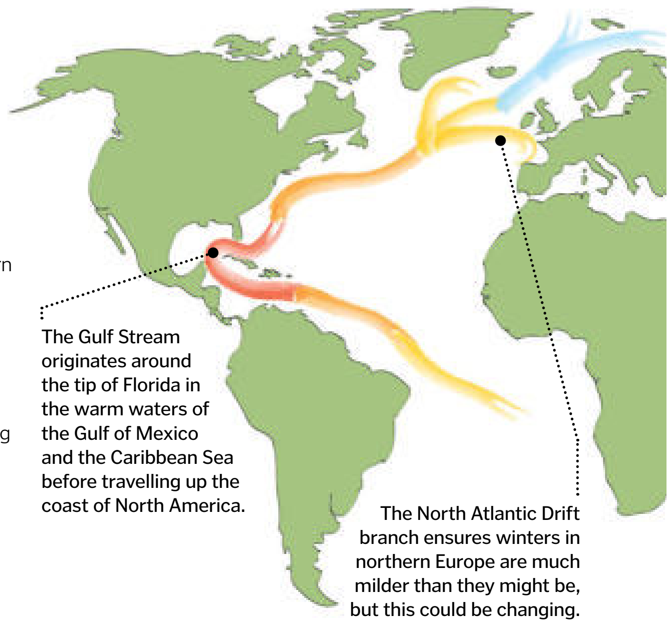
Marbles have been around for millennia with many found in Ancient Egypt

How does global warming affect the Gulf Stream?

Freya Tula

Our planet's oceans are in constant motion as dense (salty or cold) water sinks, driving a worldwide system of currents. The warm waters of the Gulf Stream increase temperatures in northern Europe by several degrees, but such currents are themselves vulnerable to changes in our climate.

Global warming is causing Arctic sea ice to melt, dumping excess freshwater into the north Atlantic. This could in turn affect the currents of dense water sinking in this region and slow down the Gulf Stream in coming years. Recent measurements seem to support this theory, but the complexity of global climate systems makes it very difficult to prove beyond doubt.
Alexandra Cheung



The Gulf Stream originates around the tip of Florida in the warm waters of the Gulf of Mexico and the Caribbean Sea before travelling up the coast of North America.

The North Atlantic Drift branch ensures winters in northern Europe are much milder than they might be, but this could be changing.

Could we ever make a Star Wars-like Lightsaber in real life?

Zack Florence (9)

Lightsabers certainly look neat – and just think how much time you'd save if you could slice your bread and toast it at the same time – but in reality you just can't get light to behave that way.

Once you have let a beam of light go – firing it out of the hilt of a Lightsaber, for instance – it will keep on travelling in a straight line for ever unless something gets in its way, so you would need something to trap light within it.

Imitation Lightsabers work in exactly this way, bouncing light around inside a semi-transparent tube-shaped 'blade'. This also lets you play at fighting with them – in reality two beams of light would just pass straight through each other, rather than clashing. The closest thing we could get to a real-life Lightsaber would actually be a beam of plasma – glowing, superhot electrically charged gas trapped in a powerful magnetic field. This is the same stuff that the Sun is largely made of, but producing it on Earth requires huge amounts of energy – a lot more than you could ever store in a tiny Lightsaber handle.
Giles Sparrow

Cheetahs can go from 0-96km/h (0-60mph) in just three seconds

Why wouldn't Usain Bolt beat a cheetah in the 100m sprint?

Jonathon Bullock

Usain Bolt might be the fastest man on Earth, but a cheetah can run 100 metres (328 feet) over three and a half seconds quicker. A cheetah called Sarah from Cincinnati Zoo, Ohio, holds the record at just 5.95 seconds. Cheetahs are faster than humans because they are smaller, which means they require less force to accelerate, and they have four legs which gives them more points of contact with the ground to push themselves forwards. But the reason that cheetahs are faster than any other four-legged animal is their incredibly flexible spine. As they run, it folds up to the point where the back legs actually overtake the front legs. This gives them an effective stride of about seven metres (23 feet) – the same as a racehorse!
Luis Villazon

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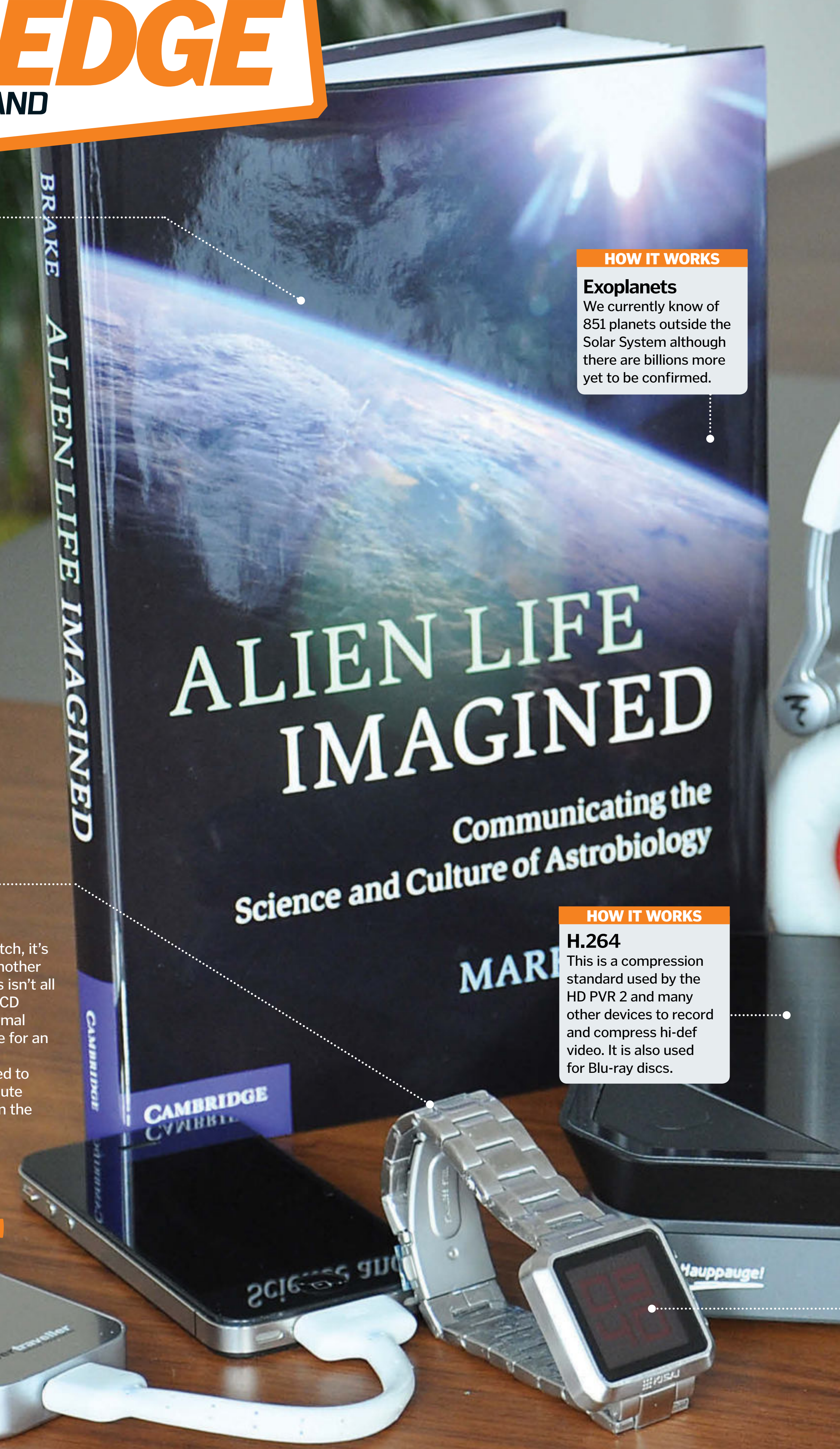

Alien Life Imagined

Price: £29.99/$45
Get it from: www.cambridge.org

Astrobiology must be a strange vocation, given that we still have no clear evidence of actual extra-terrestrial life. We've not even been able to send a man-made object outside our Solar System, let alone probe multiple star systems to give us the best chance of finding ET. It does make for a very interesting discussion though, which is what former professor Mark Brake does in this hardback title. He poses his own arguments for aliens as well as the evolution of the ideas behind extra-terrestrial life over several thousand years.

HOW IT WORKS

Exoplanets
We currently know of 851 planets outside the Solar System although there are billions more yet to be confirmed.

powermonkey discovery V2

Price: £35/$79.99
Get it from: https://powertraveller.com

In our consumer-driven society we take for granted the convenience of freely available electricity, so it's only when your car breaks down on a country road, you're stuck halfway up a mountain or at a rural festival when your phone dies that you begin to pine for a socket from which to charge. Or nearly as good and infinitely more portable, a powermonkey discovery V2 – now updated to include charging for iPhone models up to the 4S and sixth-generation iPod nano, although it supports a huge range of other portable music players and smartphones too. Fully charged, it can supply up to 180 hours of standby phone power, it's robust, reasonably priced and could truly be a lifesaver.

Kisai Maze Watch

Price: £86.19/$139
Get it from: www.tokyoflash.com

Better than having a watch that looks like a watch, it's a watch that looks like a maze. It can only be another digital timepiece from Tokyoflash. Actually, this isn't all that hard to read once you get used to it. The LCD panel can be switched from Maze mode to Normal mode if you get stuck, then back to Maze mode for an ice-breaker or talking point with retro-chic and gamer-type people at a party. This is guaranteed to make you more interesting for at least one minute while you show an admirer what happens when the time changes. The rest is up to you…

HOW IT WORKS

H.264
This is a compression standard used by the HD PVR 2 and many other devices to record and compress hi-def video. It is also used for Blu-ray discs.

HOW IT WORKS EDITOR'S CHOICE AWARD

HOW IT WORKS

USB charging
The main difference between USB 2.0 and 3.0 is a higher 900mA amperage. This shouldn't stop USB 2.0 charging though; in fact, the higher current means it should charge faster.

Hauppauge HD PVR 2

Price: £159.99/$169
Get it from: www.hauppauge.co.uk
Recording your gaming feats for posterity is an increasingly popular pastime. While software solutions are available, much better quality and reliability can be achieved using a dedicated piece of capture hardware, with US manufacturer Hauppauge leading the way. The HD PVR 2 is an update to the HD PVR, which was based on its Colossus internal desktop PC capture card tech. The main feature is up to 1080p video capture for PC and Xbox 360 at 30 progressive frames per second (1080i on PS3), plus long-awaited HDMI pass-through for playing on a TV. Hook it up to a laptop or desktop PC and start grabbing takes. If you're still struggling, there's even a simple YouTube upload button included.

Spirit One headphones

Price: £199.95/$279.99
Get it from: www.focal.com
We have an irrational pet hatred of high-end audio boutique stores – the Savile Row equivalent for audiophiles where anyone not wearing empty-framed glasses, a tweed jacket and wielding a platinum credit card is turned back out into the trendy cobbled alleyway. Focal's Spirit One headphones look like they could be found in such a place, so at first glance we expected to hate the Spirit Ones… but despite ourselves, we really enjoyed these headphones. Created with the Apple commuter in mind, they feature portable comfort and ease of use that makes them ideal for plugging in to your portable music system and immersing yourself in your tunes. And they sound fantastic too; the 40-millimetre (1.6-inch) circumaural cans do a superb job of cutting through any ambient noise and putting you at the centre of a rich personal sound system. The RRP is fairly standard for 'phones of this calibre but, if you shop around, you can get them cheaper.

HOW IT WORKS

Circumaural

Circumaural means anything that covers the pinnae, or outer ears. In headphones, it means superior sound quality over intraural audio devices – like earbuds, for example.

Zip earphones

Price: £12.99/$N/A
Get it from: www.thumbsupworld.co.uk
Let's start with the sound. It's pretty standard really – about as good as you can expect from a pair of earphones that will give you more than £7 change from a £20 note. The buds themselves are a bit small to fit comfortably in our ears, but that doesn't matter, because these are zip earphones! An innovative solution to portable earphone cable tidying that houses the left and right cables together in a single robust zip. They will probably make strangers stare at you and ask questions, but secretly, that's what you wanted, wasn't it?

HOW IT WORKS

What the EL?

Electroluminescence (EL) occurs in certain materials, like zinc sulphide doped with copper; they emit light whenever electricity passes through them.

HOW IT WORKS

Zippy physics

Zips take advantage of a fundamental property of a wedge: if you push it forward, it will exert a force perpendicular to the direction in which it is moving.

APPS OF THE MONTH

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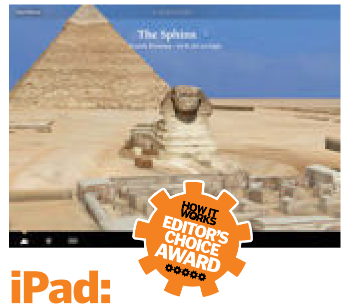

iPad: Pyramids 3D

Price: £9.99/$13.99
Developer: Touch Press LLP
Version: 1.0.1
Size: 1.07GB

Rated: 4+
Explore the stunning sights of Giza in Pyramids 3D, including the Great Pyramid and the Sphinx. With most of the pyramids and tombs you're able to enter and see the internal structures and wall paintings, complete with audio narration. You can learn about objects discovered in the area through archaeological digs, read about the history of the Old Kingdom – featuring interactive animations – and even view Then and Now images of the main landmarks. A downside of this app is that it's a whopping 1GB in size.
Verdict: 4/5

iPhone: Atlas by Collins

Price: £4.99/$6.99
Developer: Harper Collins Publishers
Version: 1.0.3 **Size:** 620MB


Rated: 4+
At face value Atlas by Collins presents a map of the world like Google Earth, but once you download extra maps to layer over the top this app gets interesting. You can view all the planet's political factions or natural resources by locations, or how tech connects us all. Unfortunately though, the app is unstable even on new devices.
Verdict: 3/5

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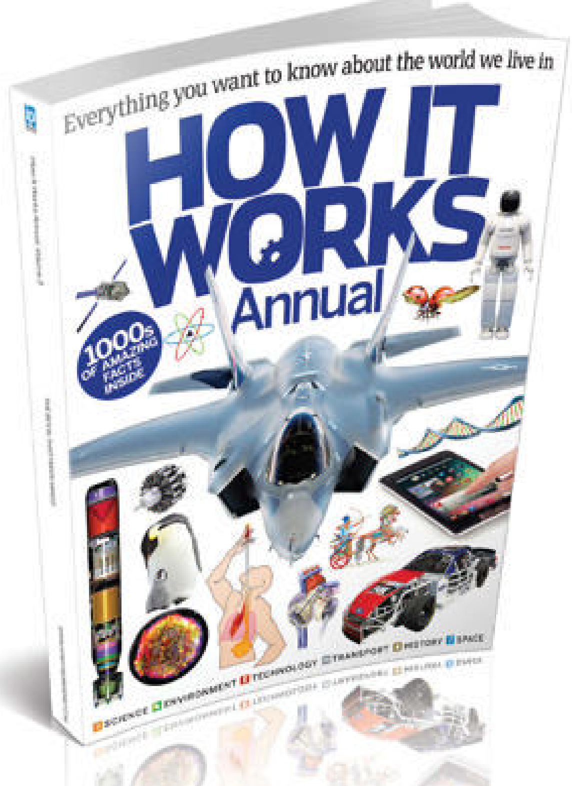

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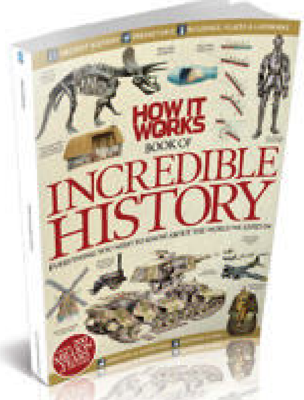

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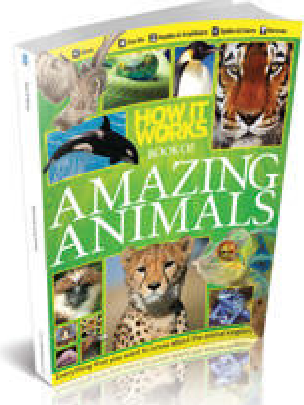

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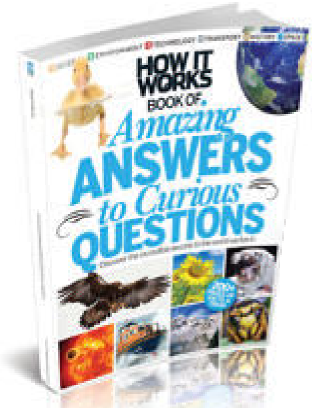

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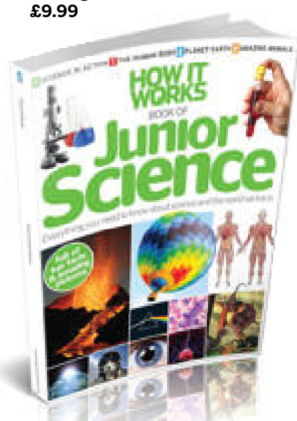

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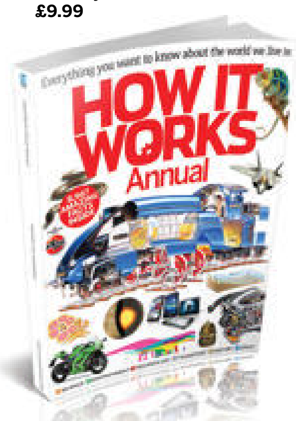

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GROUP TEST

PUTTING PRODUCTS THROUGH THEIR PACES

Budget compact cameras

Three sub-£100 cameras, each with a funky feature

PROS Very small; full-featured
CONS Some blurry night shots

PROS Great value for money
CONS Gimmicky 3D mode

PROS Sturdy; easy to use
CONS Lower-quality images

Olympus VG-170

Price: £79.99/$99.99
Get it from: www.olympus.co.uk

Of our three group test candidates the Olympus VG-170 comes the closest to feeling like a high-end compact, with its 7.6-centimetre (three-inch) screen, classic shape and wide range of shot options. It's no slouch as far as camera specifications are concerned either: it takes shots at up to 14 megapixels with a focal length equivalent to 35 millimetres (1.4 inches) and 5x optical zoom. It's more or less comparable, in this respect, to the diminutive Samsung ST66. It takes 720p video like the other two cameras, but the VG-170's flash really stands out. Apparently it's twice as powerful as the flash on a more expensive compact camera and we can believe that, as there were no problems illuminating the dark corners in the back of the room we were shooting in. The VG-170's gimmick is a 3D mode, which enables the user to take two shots that it converts into a stereoscopic three-dimensional photo. It really is just a gimmick though, as the 3D effect isn't all that convincing. Nevertheless, this is an excellent value camera for the money.

Verdict: ★★★★★

Samsung ST66

Price: £99.99/$119.99
Get it from: www.samsung.com

Wow, this is a tiny camera – Samsung wasn't kidding when it brought the ST66 into the 'compact' category. It's most definitely pocket size, looks cute and, more importantly, has a reassuringly solid build too. And pound for pound it's fairly competitive in terms of technology as well. The ST66 is decked out with a sensor capable of taking shots that are a respectable 16.1 megapixels in size. It has a 5x optical zoom that allows for up to 25x magnification with digital zoom, and the lens is a substantial 25-millimetre (0.98-inch) wide-angle, designed specifically for getting everyone in a large group shot into the photo – or for a stunning landscape if you prefer, although the ST66's Live Panorama mode is more than adequate for taking 180-degree images. The main feature of the ST66 is the F2.5 bright lens that is designed with the night owl and socialite in mind. It lets you take much clearer shots in the dark, although in practice there is sometimes a bit of blurring despite the camera's built-in digital image stabilisation (DIS) tech.

Verdict: ★★★★☆

Nikon Coolpix S30

Price: £79.99/$119.95
Get it from: www.nikon.com

Nikon describes the Coolpix S30 as a family camera 'made to fit comfortably in hands of any size', but although the form factor is quite small the Samsung featured in this roundup is around half its size. However, we can't deny that it's definitely a family-friendly camera in general. The S30 has a relatively modest ten-megapixel image resolution, a 3x optical zoom, a high-resolution 6.7-centimetre (2.7-inch) screen and an anti-blurring feature, which works rather well. It also boasts the most simplified and easy-to-use digital camera interface we've seen yet, which includes a good variety of 'fun filters' that offer the usual slew of fisheye lens and colour effects to spice up your snaps. The S30 is also waterproof to a depth of three metres (9.8 feet) and shockproof to 0.8 metres (2.6 feet). The latter might not sound an especially impressive spec, but sure enough the S30 survived just fine when we dropped it from around waist height. It's certainly a tough cookie, which has to be one of its most child-oriented qualities.

Verdict: ★★★★☆

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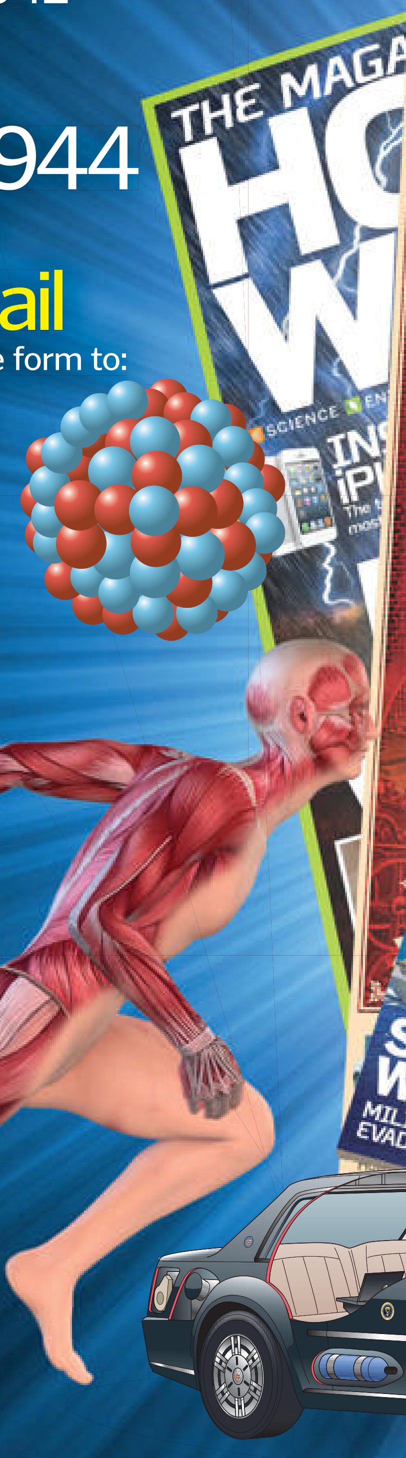

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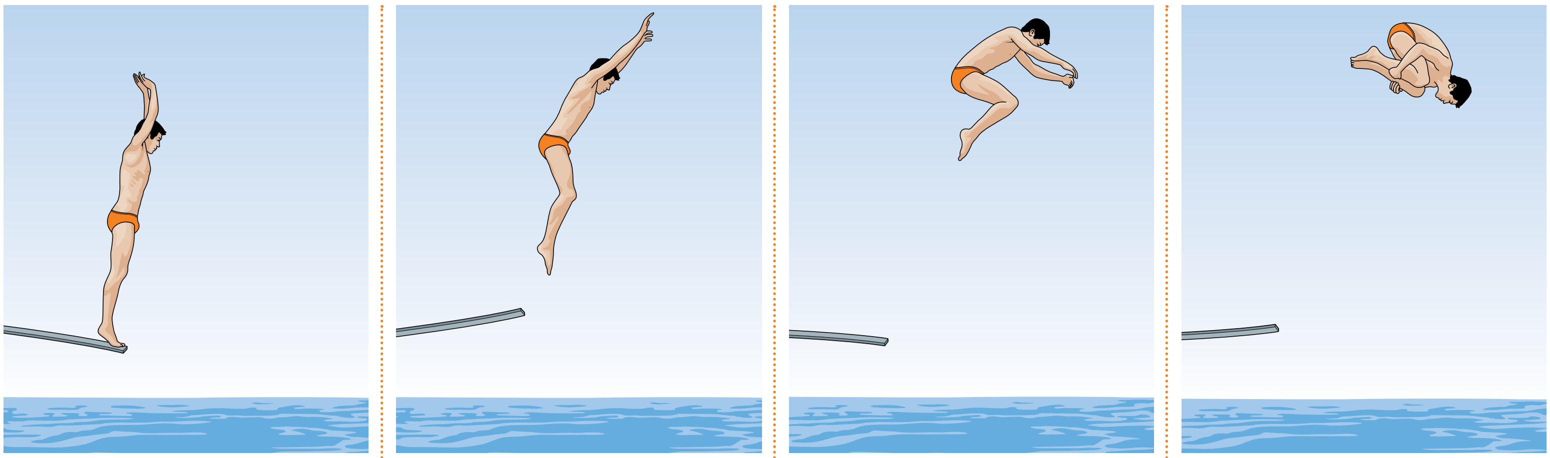


1 Potential energy

Standing on the high board a diver has a set amount of potential energy. While this potential is simply converted into kinetic energy when performing a straight dive, in a high-diving situation, it is not sufficient to grant the diver adequate power and momentum to rotate their body for more complex manoeuvres. This is gained by the addition of a springboard, which when jumped on by the diver, oscillates and stores additional potential energy that it releases rapidly.

2 Defy gravity

The release of potential energy from the springboard delivers a force large enough to overcome gravity, propelling the diver high into the air above the pool. At this point the diver has a great deal of kinetic energy and momentum, which is expressed over a specific trajectory. The trajectory will lead the diver to the pool, however neither of these factors will have a big effect on the diver's physical position while either in the air or upon making contact with the water.

3 Getting in a spin

For divers to position themselves correctly, and to perform mid-air stunts like a somersault, they need to introduce rotational energy into the mix. The diver achieves this by throwing their arms downwards at the apex of the trajectory in order to force their upper torso to rotate around the hips, while at the same time drawing up their legs. The diver's body proceeds to pivot around an invisible axis, positioning themselves upside-down and perpendicular to the water.

4 Master inertia

As dictated by the laws of motion, during the diver's rotation there is conservation of angular momentum. This is not obvious with straight dives, but is far more visible – and critical for success – for a somersault dive. Here the diver's body needs to rotate at a quicker rate to cover the greater angular distance, which is achieved by reducing the diver's motion of inertia. This reduction in inertia is accomplished by drawing in the arms and legs so that they form a ball shape.

Build a snowman

Three tips on the art of making snowmen

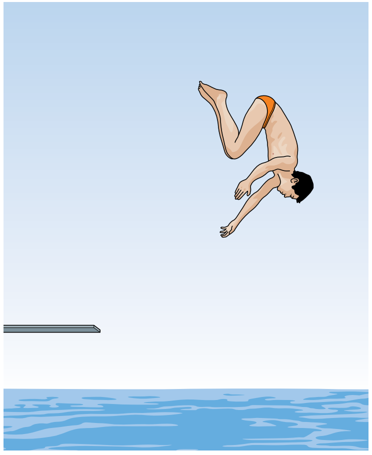
1 Location and material

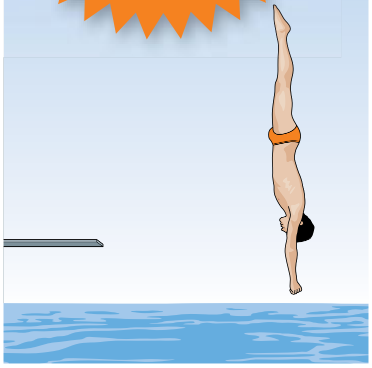
Firstly a snowman will last far longer if provided with a bit of protection from the elements. Try to build under a tree or next to your house – also, build on an even surface. In terms of material, wet snow works best. Dry fluffy snow is pretty but useless for this task. Lastly, while rolling a ball of snow around is the traditional way of gathering a base, a large shovel is much more efficient.

2 Sculpting and detail

Once you have enough snow in a mound, pack it as firmly as you can into the rough size and shape of the body. Now we can sculpt. The best tools for this are spatulas, spoons and trowels. Begin from the bottom, carefully removing small sections to add details like feet, legs and the torso, before moving on to the head. Level off the mound at the neck to create a level surface to attach the head.

NEXT ISSUE
- Plant a veg patch
- Skateboard like a pro





5 Conservation

In order to slow and then stop the rotation, the diver must increase their moment of inertia by coming out of the ball shape and straightening their body. This conserves momentum and creates resistance to rotational motion. Timing this latter process is critical, as while conserving momentum can mitigate the chances of overshooting the somersault and belly-flopping onto the water, the diver must still leave necessary time during the drop to complete the manoeuvre.

6 Making contact

Regardless of the number of somersaults or twists that have been performed by the diver in the air, entering the water cleanly requires the body to be totally perpendicular to the surface. Keeping the contact surface area as small as possible is the key to a professional finish, with the diver pulling their arms and legs into their body to form a narrow column. This reduces noise, splash and – most importantly when making contact at high velocity – impact on the body.

In summary…

First, the higher you are positioned relative to the pool, the more potential energy you have for a longer, faster dive. Secondly, rotational motion is key to entering the water with minimal resistance and for performing any sort of flip/somersault. Thirdly, drawing in your arms and feet while rotating will reduce your moment of inertia so you'll spin faster. Fourthly, you can reduce rotational energy by straightening limbs. Finally, contact with the water should be perpendicular, with the body kept poker straight for a clean entry.

3 Dressing up

Once the body is made, it's time to dress your creation. Eyes are traditionally made with lumps of coal, but round stones, buttons or coins can also work – the same is true of any buttons for the clothes. Noses can be any old vegetables, though carrots are the norm. Arms can be fashioned by slotting branches into the torso, while old hats, scarves and gloves can all add an extra touch of realism.

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TEST YOUR KNOWLEDGE

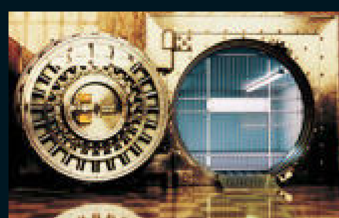
ENJOYED THIS ISSUE? WELL, WHY NOT TEST YOUR WELL-FED MIND WITH THIS QUICK QUIZ BASED ON THIS MONTH'S CONTENT?

1 In which year was Sir Isaac Newton born?
A: ______

2 Reportedly how much is a Cadillac One in US dollars?
A: ______

3 What size engine does the Pit-Bull VX have?
A: ______

4 Which is the 15th-largest moon in the Solar System?
A: ______



5 How heavy is the world's heaviest bank vault door?
A: ______

6 In what period did the Tyrannosaurus rex live?
A: ______

7 How many ribs are there in the human body?
A: ______

8 Which ancient empire built the Angkor Wat complex?
A: ______

9 How long did Neil Armstrong spend on the Moon's surface during the Apollo 11 mission?
A: ______

10 What is the cheetah world record for running a distance of 100 metres?
A: ______

ENTER ONLINE

at **www.howitworksdaily.com** and one lucky reader will win a model of the lead Type 45 destroyer from the Royal Navy, HMS Daring

> ISSUE 41 ANSWERS
1. Franklin D Roosevelt **2.** 3.75MB **3.** 1.8 microseconds **4.** Petals **5.** 1,500LY **6.** 58,967kg **7.** 6.7l **8.** 1571 **9.** Who will "rid me of this turbulent priest?" **10.** 33,114

INBOX

Feed your mind. Speak your mind

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Win! A WOWee One portable speaker

The Forbidden City at the heart of Beijing; inset: a map from 1626 with Xanadu in the top-right

Get in touch!

We enjoy reading your letters every month. So keep us entertained by sending in your questions and views on what you like or don't like about the mag.

FANTASTIC PRIZE FOR LETTER OF THE MONTH!

WOWee ONE™

WIN A WOWEE ONE PORTABLE SPEAKER

This issue's top letter wins a WOWee One Classic portable speaker. This turns any surface into a bass amplifier using gel technology, and is compatible with all iDevices and other mobile gadgets.

Letter of the Month

I Khan't find Xanadu!

Hi HIW

I was reading the article on China's Forbidden City in issue 40 [page 80-81] and was intrigued by the mention of Xanadu, which you say was a former capital of the country. Basically, I'm writing in to see if you can supply a little more information about this city and where it is located, as I can't seem to find it anywhere on my world map!

Annabelle Kent

Hi Annabelle, we're glad you enjoyed the article on the Forbidden City. Xanadu was the summer capital of Kublai Khan's Yuan Dynasty (1279-1368) in China, which he lived in and conducted government from during the hottest months of the year. It was first described in the west by famous Venetian explorer Marco Polo in 1278, who stated that it consisted of a large walled city with a central marble palace that encompassed approximately 41 square kilometres (16 square miles) of terrain. Today, Xanadu is located in Inner Mongolia, approximately 350 kilometres (220 miles) north of Beijing and 27 kilometres (17 miles) north-west of the town of Duolun. Unfortunately – and probably the reason you've been unable to locate it on your map – it is now in a completely ruinous state, though it was recently named a UNESCO World Heritage Site in July 2012. Enjoy your WOWee portable speaker!

No poster as yet, but the content from previous issues is available on disc

Impressive decay

Dear Sir/Madam,

Some time ago a pupil showed me a spread from one of your magazines which showed the effects of radiation and in particular a very impressive decay chain starting with uranium-238 and finishing with lead-206. I wonder if you, by any chance, ever happened to make an educational poster out of this two-page spread, as it is a mine of information.

Best regards,

John Devitt

Thank you for your kind words, John. Unfortunately, there are currently no plans to produce a standalone poster of that spread from our 'Nuclear radiation' feature in issue 12. However, all is not lost, as that issue's content appears on the How It Works eMag Vol 1. All content on the eMag can be printed out in high resolution for situations just like this.

Best thing since sliced bread

Hello,

I thought this magazine was the best thing since sliced bread… until my magazine began to fall apart that is! The centre page parted from the staples, which rather spoilt my enjoyment until I managed to get most of it back in order. I still enjoy it though and hope it stays complete from now on. Many thanks for a very interesting mag.

Bob Frayling

Stuck in a bind

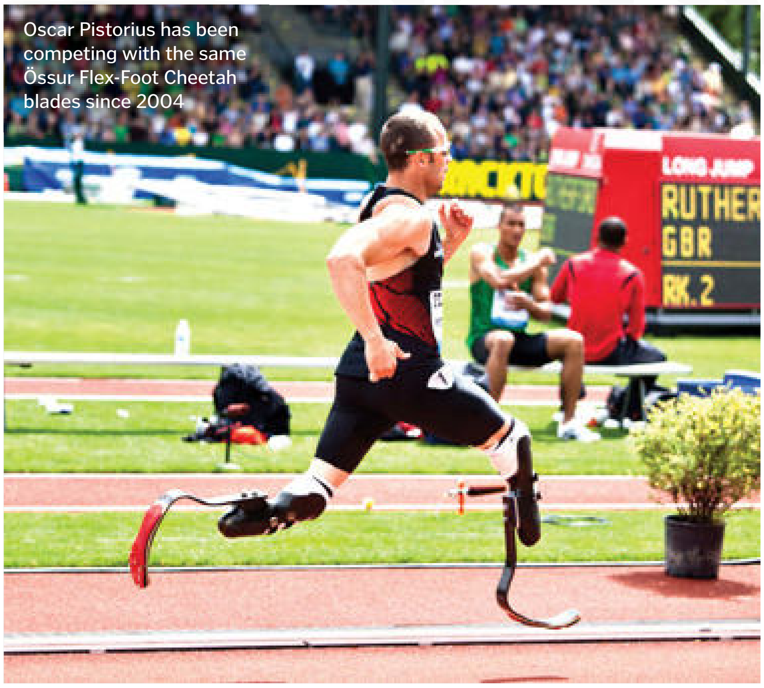
Good morning,

I subscribe to your wonderful magazine and I am looking for suitable binders to store them. Do you sell them please? Unfortunately, the size of the mag does not suit normal A4 off-the-shelf binders. I look forward to hearing from you.

Regards,

Mike Hardy

Hi Mike, you've raised an interesting point. While currently we have no official binders for sale through the Imagine Shop, funnily enough we are getting this request quite frequently. As a result, plans are afoot to look into the feasibility of introducing some form of HIW binder in the near future. Watch this space!



Oscar Pistorius has been competing with the same Össur Flex-Foot Cheetah blades since 2004

Oscar's blades of glory

I'm doing a project at school on Oscar Pistorius, the Paralympic/Olympic athlete. What I want to know is: how does the shape and material of his blades help him to run? Thanks for such a great mag!
Stan Roynon (11)

Blades, as worn by Oscar Pistorius, are made from lightweight carbon fibre and shaped to mimic the hind legs of a cheetah – which is the fastest animal on Earth. The blades are J-shaped so that as the athlete runs they become compressed on impact, storing energy and stress. As such, when the runner lifts off with that leg, the stored energy is released at a rapid rate, propelling them forward at high speed. This action replaces that which is delivered in able-bodied athletes by their feet, ankles and lower leg muscles. For a more detailed explanation of running blades, see HIW issue 14 (page 22). Good luck with your project, Stan!

Myth-busting Late Cretaceous style

Hi,

Just writing in to say that after reading your 'Top 5 Velociraptor myths' section in issue 38 [page 77] I can't believe how distorted my view of Velociraptors had become thanks to films like *Jurassic Park*. I knew they were more turkey sized than the ones portrayed in the movies, but as for the rest, I had no idea… wow! Thanks for the info,
Tom Snow

What's happening on… Twitter?

We love to hear from **How It Works**' dedicated readers and followers, with all of your queries and comments about the magazine and the world of science, plus what you'd like to see explained in future issues. Here we select a few of the tweets that caught our eye over the last month.

@oneplanetwoman
@HowItWorksmag
Might be simple but a basic science guide to everyday technology would be great. Flat-screens, Nespresso machines, etc :)

@Fritzy
@HowItWorksmag
Does transmutation of elements happen anywhere apart from stars?

@hectorini16
@HowItWorksmag
How does a vortex cannon work?

@bowbrick
@HowItWorksmag
My son's @HowItWorksmag sub has become my favourite read. There's a lovely feature on the Industrial Revolution in this month's issue: http://t.co/k8aZNhzm

@GlitterballGlam
@HowItWorksmag
Humans get a little taller in space because there is no gravity pulling down on them. #Sciencefact

HOW IT WORKS

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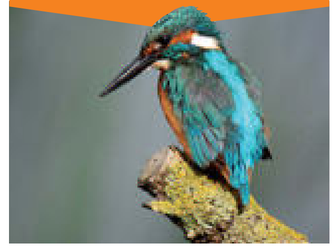
ANSWERED NEXT ISSUE

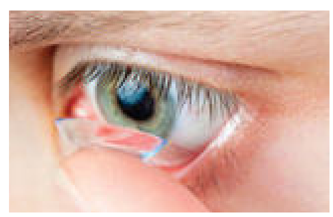


How do kingfishers catch fish on the wing?

Why does the Moon go red during an eclipse?

How did the Battle of Little Bighorn play out?

Why was the planet's biggest drain built?



How is the prescription added to contact lenses?

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